Groundwater Monitoring Plan

Former Tronox Pigments Site
100 SeaPoint Boulevard
Savannah, Chatham County, Georgia
HSI No. 10179

September 1, 2021 (revised June 3, 2022)
Terracon Project No. ES177321L

Prepared for:

Georgia Environmental Protection Division
Atlanta, Georgia

Prepared by:

Terracon Consultants, Inc.
Savannah, Georgia

Terracon

September 1, 2021 (revised June 3, 2022)

Georgia Environmental Protection Division
Hazardous Waste Corrective Action Program
2 Martin Luther King Jr. Drive, Suite 1054
Atlanta, Georgia 30334-9000

Attn: Mr. Jim McNamara, Program Manager

Re: Groundwater Monitoring Plan
Former Tronox Pigments Site
100 SeaPoint Boulevard
Savannah, Chatham County, Georgia
Terracon Project No. ES177321L

Dear Mr. McNamara:

On behalf of Sulfco, LLC, Terracon Consultants, Inc. (Terracon) respectfully submits this Groundwater Monitoring Plan (GMP) for the above-referenced site. The purpose of this GMP is to outline the protocols and process for the site's groundwater monitoring in accordance with the approved Prospective Purchaser Corrective Action Plan (PPCAP), completed by Tetra Tech, Inc (Tetra Tech) and approved by the Georgia Environmental Protection Division (EPD) on July 19, 2017 for the Former Tronox Pigments Plant (Savannah), GAD003282803. Once final approval is obtained from the Georgia Environmental Protection Division (EPD), this GMP will be initiated in accordance with the approved remedial alternatives designated in the PPCAP.

If you have any questions or comments pertaining to the material presented herein, please contact the undersigned at (912) 629 4000.

No. 20997
WILLIAM S. ANDERSON III

Sincerely,
Terracon Consultants, Inc.

Anthony Ellison

Wm. Anthony Ellison, PG
Project Geologist

William S. Anderson, III, PE
Senior Vice President

Cc: Mr. Philip Rowland/Sulfco
Mr. Joseph Blackmon/Sulfco
Mr. Jim McNamara/Georgia EPD
Ms. Cynthia Brooks/Greenfield Environmental Savannah Trust, LLC
Mr. Craig Kaufman/Greenfield Environmental Savannah Trust, LLC
Mr. Jeff Strand/Greenfield Environmental Savannah Trust, LLC

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Design and Installation of Monitoring Wells, SESDGUID-101-R1, effective date January 29, 2013.

Field Equipment Cleaning and Decontamination, LSASDPROC-205-R4, effective date June, 22, 2020.

Field pH Measurement, SESDPROC-100-R4, effective date December 16, 2016.

Field Measurement of Dissolved Oxygen, SESDPROC-106-R4, effective date April 12, 2017.

Field Sampling Quality Control, SESDPROC-011-R5, effective date April 26, 2017.

Field Specific Conductance Measurement, LSASDPROC-101-R7, effective date May 5, 2020.

Field Temperature Measurement, SESDPROC-102-R5, effective date March 14, 2018.

Field Turbidity Measurement, SESDPROC-103-R4, effective date July 27, 2017.

Groundwater Level and Well Depth, LSASDPROC-105-R4, effective date May 15, 2020.

Groundwater Sampling, SESDPROC-301-R4, effective date April 26, 2017.

APPENDIX D Existing Well Boring Logs and Well Construction Diagrams

ACRONYMS AND ABBREVIATIONS

Term	Definition
ASTM	ASTM International
bgs	below ground surface
COCs	contaminants of concern
DO	dissolved oxygen
DTW	depth to water
EPA	United States Environmental Protection Agency
EU(s)	exposure unit(s)
EPD	Georgia Environmental Protection Division
GMP	Groundwater Monitoring Plan
HSRA	Hazardous Site Response Act
HQ	hazard quotient
LUCs	land use controls
LSASD	EPA Laboratory Services and Applied Sciences Division
LWBZ	lower water bearing zone
mg/L	milligrams per liter
mL/min	milliliters per minute
mL	milliliters
MSL	mean sea level
mV	millivolts
MS/MSD	matrix spike/matrix spike duplicate
NAD83	North American Datum of 1983
NAVD88	North American Vertical Datum of 1988
NELAP	National Environmental Laboratory Accreditation Program
NSF	National Sanitation Foundation
NTU	nephelometric turbidity units
OCGA	Official Code of Georgia Annotated
ORP	oxidation-reduction potential
PPCAP	Prospective Purchaser Corrective Action Plan
PVC	polyvinyl chloride
QA/QC	quality assurance/quality control
RPD	relative percent difference
RA(s)	remediation area(s)
RAO	remedial action objectives
RCRA	Resource Conservation and Recovery Act
RFI	RCRA Facility Investigation
RRS	Risk Reduction Standard
Savannah Trust	Greenfield Environmental Savannah Trust, LLC.
SESD	EPA Region 4 Science and Ecosystem Support Division
Site	100 SeaPoint Boulevard, Savannah, Georgia
SOP	standard operating procedure
SU	standard units
SVOC	semi-volatile organic compound
TiO_2	titanium dioxide
UWBZ	upper water bearing zone
VOC	volatile organic compound

REPRESENTATIONS

OWNER CERTIFICATION

I certify under penalty of law that this document and all attachments were prepared under my direction or supervision according to a system designed to assure that qualified personnel properly gather and evaluate the information submitted. Based on my inquiry of the person or persons who manage the system, or those persons directly responsible for gathering the information, the information submitted is, to the best of my knowledge and belief, true, accurate, and complete. I am aware that there are significant penalties for submitting false information, including the possibility of fine and imprisonment for knowing and failing to communicate violations.

Dulany Industries, Inc.

By: ____

Name: Philip Rowland, Vice President
Dulany Industries, Inc.

REGISTERED PROFESSIONAL CERTIFICATION

I certify that I am a qualified groundwater scientist who has received a baccalaureate or postgraduate degree in natural science or engineering and have sufficient training and experience in groundwater hydrogeology and related fields, as demonstrated by state registration and completion of accredited university courses, that enable me to make sound professional judgements regarding groundwater monitoring and contaminant fate and transport. I further certify that this report was prepared by me or by a subordinate working under my direction.

I certify that this Groundwater Monitoring Plan (GMP) was prepared under my direction and that I supervised and directed the engineering associated with preparation of the GMP. The information, figures and appendices in the GMP are, to the best of my knowledge, true, accurate, complete, and in accordance with State Rules and Regulations.

Name: William S Anderson, III, PE

Signature: ______________________________

Date: ______________________________

No. 20997
WILLIAM S. ANDERSON III

Georgia Stamp

GROUNDWATER MONITORING PLAN

FORMER TRONOX PIGMENTS SITE
Savannah, Chatham County, Georgia
HSI No. 10179

Terracon Project No. ES177321L
September 1, 2021 (revised June 3, 2022)

1.0 INTRODUCTION

The Former Tronox Pigments Site is located at 100 SeaPoint Boulevard (formerly known as Kerr-McGee Road), Savannah, Chatham County, Georgia (Site) and has initiated remedial activities outlined in the Prospective Purchaser Corrective Action Plan (PPCAP) completed by Tetra Tech, Inc. (Tetra Tech) and approved by the Georgia Environmental Protection Division (EPD) on July 19, 2017. The Site was transferred from Tronox to the Greenfield Environmental Savannah Trust LLC, Trustee of the Savannah Environmental Response Trust (the Savannah Trust) on February 14, 2011. Sulfco, LLC, a subsidiary of Dulany Industries, Inc., purchased the Site from the Savannah Trust in late September 2017. The location of the site is shown on Figure 1 in Appendix A.

A Groundwater Monitoring Plan (GMP) is required to evaluate the effectiveness of the remedial actions and to confirm that the Land Use Controls (LUCs) as implemented maintain long-term protections for human health and ecological receptors. Included within this GMP are defined parameters for chemical analysis, frequency of sample collection, procedures and techniques for sample collection, sample preservation and shipment, analytical methods, chain-of-custody control, the monitoring well system design and installation, and reporting of well construction and monitoring results.

The GMP is generally consistent with Chapter 391-3-4-.14 *Groundwater Monitoring and Corrective Action* of the Georgia EPD Solid Waste Management Rules and the EPD's Manual for Groundwater Monitoring. The GMP will conform with the groundwater monitoring program described in the PPCAP. Deviations from the PPCAP will be proposed in the GMP, and the rationale / justification including supporting documentation provided for EPD’s review. The GMP also conforms to the current U.S. Environmental Protection Agency Region 4 guidance, which is digitally available at *https://www.epa.gov/quality/quality-system-and-technical-procedures-sesd-field-branches* with relevant Standard Operating Procedures (SOPs) included in Appendix C.

2.0 SITE SUMMARY

The Site's total footprint identified in the PPCAP was approximately 1,570 acres including 560 acres of uplands and 1,010 acres of undeveloped wetlands. The Site currently encompasses approximately 756.2 acres with the remaining portions deeded to the State of Georgia. The heavy industrial developed area of the Site encompasses a total of 194 acres. Historic usage of the Site was agricultural up to the 1880's. From approximately 1921 to 1954 the City of Savannah operated the Deptford Tract Landfill on the southwest portion of the Site. The recent usage of the Site included a heavy industrial area that encompasses a total of +/-194 acres and began in the 1950's. The primary uses included a titanium dioxide (TiO_2) plant with a sulfate production process, a sulfuric acid plant, a chloride process area, wastewater sludge ponds, in-plant neutralization operations and basins, dredged sludge filter press area, and a dredged spoils storage area. The southwestern portion of the property was leased and/or used for other purposes including a municipal solid waste incinerator, a gas separation plant, a gypsum plant, a municipal landfill (aforementioned Deptford Tract Landfill), and a water treatment chemical manufacturing facility. In December 2009, all operations at the Site ceased apart from production at the sulfuric acid plant. The Deptford Tract Landfill area has an existing EPD approved Corrective Action Plan which includes ongoing groundwater monitoring and reporting that is conducted under the direction of the City of Savannah. As such, this GMP does not include the Deptford Tract Landfill area.

2.1 Summary of Previous Environmental Investigations

In 2016, Tetra Tech completed a Resource Conservation and Recovery Act (RCRA) Facility Investigation (RFI) to determine the nature and extent of contaminant concentrations in exceedance of background concentrations at the Site. Soil, sediment, and groundwater background data sets were developed to differentiate Site-related releases from contaminants inherent to the fill material used to develop and construct the Site. The Site was divided into 16 Exposure Units (EUs) based on the risk assessment, site characterization, media type, media migration pathway, regulatory requirements, and expected remediation scenarios.

The identified EUs are as follows:

- EU01 – Saltwater Mitigation Bank;
- EU02 – Gypsum Plant-Plant Operations;
- EU03 – Gypsum Plant-Materials Storage Area;
- EU04 – Causton Bluff Dredge Spoils Area;
- EU05 – Marcona Area;
- EU06 – Municipal Solid Waste Incinerator;

- EU07 – Occupied Area-Kemira Water Solutions;
- EU08 – Air Liquide;
- EU09 – In Plant Neutralization Basin and Related Areas;
- EU10 – Current Ponds and Sediment Management Areas;
- EU11 – Former Ponds;
- EU12 – Former Sulfate Area/Northwest River Bank/Administrative Areas;
- EU13 – Contractor’s Village/Original Pond 1;
- EU14 – Former Chloride Process Area;
- EU15 – Perimeter Areas; and
- EU16 – Fort Jackson Buffer Area.

A higher-order grouping of the EUs into designated Remediation Areas (RAs) was completed to isolate the potential remediation alternatives into segregated boundaries within the full Site footprint. The RA boundaries were based on source-specific contaminants, media type and potential remedial alternatives. The RAs are identified as the following:

- Developed Area (EUs 05, 06, 09, 12, 13, and 14);
- Dredged Spoil Area-Filter Press Area, Geotube Area, and Pond Spoil Piles 1 and 2 (EU10);
- Inactive Pond (IP) Area-Ponds 1, 2, 3, and 4 (EU11);
- Active Pond (AP) Area-Ponds 5 and 6 (EU10);
- Perimeter Area Sediment (EU15);
- Emergency Ditch (EU15); and
- Groundwater (site-wide).

Other EUs not requiring defined remediation activities based on human health or ecological risk as identified in the RFI include the following:

- Saltwater Mitigation Bank (EU01);
- Former Gypsum Plant and Gypsum Storage Piles (EU02 and EU03);
- Causton Bluff Dredge Spoil Area (EU04);
- Kemira Water Solutions area (EU07);
- Air Liquide area (EU08); and
- The Fort Jackson Buffer area (EU16).

The limits of the EUs and the RAs are depicted in the figures included in the PPCAP plan sheets.

2.2 Summary of Remedial Alternatives by Area

The Developed Area includes the primary EUs associated with the former TiO_2 plant, sulfate plant, chloride plant, ancillary rail line areas, the former incinerator, and the current Southern States Chemical acid plant. The selected remedial alternative for this area is the removal of discrete areas of elevated concentrations of Contaminants of Concern (COCs) or capping of the discrete area with existing concrete pads in combination with LUC.

The Dredged Spoil Area includes the Filter Press Area, Geotube Area, and Pond Spoil Piles 1 and 2. These are areas of fill that utilized dredged material from Ponds 5 and 6 following temporary stockpiling and/or liquids removal in the Filter Press Area. The selected remedial alternative for these areas includes consolidating waste media into limited waste containment areas and capping the waste footprint limits with a low-permeability soil in combination with LUCs.

The IP Area encompassing former Ponds 1, 2, 3, and 4 received mixed waste streams from both the sulfate and chloride processes associated with the TiO_2 production. These areas were filled above grade with steep and irregular side slopes and contained relatively dry, consolidated dredge material. The selected remedial alternatives for this area include 1) grading the excessively steep waste material slopes, 2) redistributing the excess material to low areas to promote drainage, and 3) capping in-place with a low permeable soil in combination with LUCs.

The AP Area is confined to the former Ponds 5 and 6 limits which were used in conjunction with the in-plant neutralization basins. These ponds were filled with saturated waste material contained within exterior berms. The AP Area was separated from the IP Area due to the differing fill conditions and waste media consistency. The selected remedial alternatives for this area include 1) the grading and consolidation of waste material to promote drainage and 2) capping in-place with a low permeable soil in combination with LUCs.

The Perimeter Area Sediments includes various lowlands located between former industrial areas and the adjoining wetlands. These areas were identified as potential areas of contaminant migrations due to surficial discharges outside of the primary operation areas. The selected Remedial Alternative is the removal of defined Hot Spots that are variably distributed throughout the Perimeter Area Sediment primarily associated with the former Waste Incinerator.

The Emergency Ditch previously bordered Pond 5 and 6 and was used to prevent flooding of the facility and in-plant neutralization operations. The selected remedial alternative for this area includes the removal of contaminated material and placement within the final boundary within the Dredged Spoil Area, IP Area or AP Area.

The site-wide Groundwater in both the Upper Water Bearing Zone (UWBZ) and Lower Water Bearing Zone (LWBZ) was identified as a designated RA due to extent of contamination in various areas throughout the Site. The selected remedial alternative includes the long-term monitoring of groundwater in combination with LUCs specific to prohibitions of activities that could expose human receptors to the Site groundwater.

2.3 Summary of Groundwater Land Use Controls

Portions of the UWBZ and LWBZ pose a risk to non-residential Site users based on the exceedances to the groundwater remediation goals or action levels identified in the PPCAP. The Site will seek coverage under the Type 4 and Type 5 Risk Reduction Standards (RRS) process to include LUCs in the form of engineering and institutional controls and environmental covenant restrictions that prohibit the use of groundwater as drinking water within the property boundary. The locations and extent of the proposed Type 4 and Type 5 RRS boundaries are depicted on Figures 2 through 4 of Appendix A.

The proposed Type 5 RRS areas identified in Figure 2 and within the property boundary have been defined as areas that potentially pose risk to construction workers through direct exposure to groundwater or inhalation of vapors during excavation operations, and future industrial worker's exposure to vapor intrusion within buildings. Some of these areas also potentially pose a potential vapor intrusion risk associated with buildings that may be constructed in the future. Buildings in these areas may require foundation vapor barriers to protect industrial workers and future building occupants. Buildings proposed in these areas without engineering controls may be allowed, provided they are first determined to be free of unacceptable risk to occupants, industrial workers, and other potential receptors by a licensed or registered environmental engineer.

3.0 GROUNDWATER MONITORING OBJECTIVES

The remedy construction in each of the RAs was designed to reduce risks to and be protective of human health and the environment, maintain that protection over time, and comply with federal and state requirements. The following Remedial Action Objectives (RAOs) were developed for groundwater at the Site:

- **Groundwater RAO No. 1:** Prevent unacceptable cumulative risks (ILCR of 1×10^{-6} or HI exceeding 1) from residential and non-residential exposures to groundwater COC concentrations exceeding approved cleanup goals, via ingestion, dermal contact, or inhalation of vapors and/or aerosol phase.
- **Groundwater RAO No. 2:** Prevent unacceptable cumulative risks associated with residential and non-residential exposures via vapor intrusion to COC concentrations in indoor air that exceed risk-based levels.

- **Groundwater RAO No. 3:** Protect surface water from potential migration of groundwater containing COC concentrations that pose current and/or future risk to ecological receptors.

The groundwater monitoring program will evaluate the overall effectiveness of the remedies applied at each RA. Following implementation of these remedies, groundwater contaminant concentrations are expected to remain stable or decrease over time because of removal of source materials and limitation of stormwater infiltration through the waste in the contained areas. The potential pathways of contaminant migration within each RA are proposed to be monitored via a network UWBZ and LWBZ groundwater monitoring wells depicted in Figure 2. Following the completion of remedial construction within each RA the individual groundwater wells associated with that RA will be installed and the 30-year monitoring period will begin. The individual RAs and their monitoring wells are separated into the Developed Area wells, the Waste Containment Area wells, and the Gypsum/Incineration Area wells. The location of the wells within the monitoring well network is appropriate to evaluate remedy effectiveness. Proposed Developed Area, Waste Storage Area and LUC groundwater monitoring wells have the following objectives:

- **Developed Area Hot Spots/LUC Monitoring Wells:** These wells will monitor the existing contaminant plumes in the Developed Area, as well as groundwater at locations downgradient of remediated hot spots. Hot spots in the Developed Area of the Site were defined based on exceedances of direct contact remediation goals and GWP action levels. Groundwater monitoring will assess the stability of the groundwater plumes in these areas.
- **Waste Storage Area/LUC Monitoring Wells:** These wells will monitor the existing contaminant plumes associated with the Dredge Spoil and Pond Areas at perimeter monitoring points. Groundwater concentrations measured in these wells will indicate increases or decreases of plume concentrations, as well as exceedances of established remediation goals and action levels. Long-term plume concentrations are expected to remain the same or decrease over time.

Groundwater Monitoring at the Site will be consistent with the Hazardous Site Response Act (HSRA), RCRA, the Georgia Solid Waste Rules, and the PPCAP prepared for the facility. The final groundwater monitoring analyte list herein includes COCs associated with Site releases that are subject to potential migration. These analytes will be monitored to determine contaminant concentration trends as well as exceedances of established remediation goals and action levels. The analytes included in Table 1 of Appendix B have been selected specifically to evaluate the effectiveness of the remedial activities at the Site. Table 1 also indicates the groundwater monitoring parameters with established cleanup goals and the additional groundwater parameters for monitoring but not requiring reporting as cleanup goals have not been established for these analytes.

4.0 GEOLOGIC CONDITIONS

A summary of the geological conditions at the Site are included in this GMP. Information was obtained from *Section 2.2 Geology* of the PPCAP and based on the findings of the RFI.

4.1 Site Geology

The regional geology of the Site location is within the Atlantic Coastal Plain consisting of consolidated and unconsolidated sands, clays, and calcareous sediments of the Late Cretaceous to Holocene Age. The surficial unconsolidated soils extend to a depth of approximately 200 feet below ground surface (bgs) with the calcareous layers extending and additional 1,000 feet in thickness. The lower bedrock is composed predominantly of metamorphic and igneous rock sloping from the central portion of the state eastward to the coast.

The localized uppermost geologic conditions around the Site are predominantly composed of fine-grained, well-sorted sand in thicknesses of 7 to 20 feet in the uplands. Large areas of wetlands consisting of unconsolidated native marsh sediment contain soft clays and plant detritus. These upper geologic layers are underlain by 5 to 45 feet of post-Miocene marsh clay deposits that act as an intermediate aquitard. Underlying these deposits is 10 to 30 feet of coarser grained post-Miocene sands with silts and discontinuous clay seams. The Miocene coarse-grained deposits are underlain by an approximately 140 feet thick Hawthorn Formation clay unit. Underlying the Hawthorn Formation are calcareous sedimentary rock composed of limestone and dolomite of the Oligocene age and older.

The upland developed, and industrialized areas of the Site are largely composed of varied layers of “made land” via fill with dredged material, waste from the Deptford Tract Landfill, TiO_2 process waste material, and other fill material. This material was placed over the native marsh sediment to raise the existing grades to allow for industrial development.

4.2 Site Hydrogeology

There are three aquifer zones within the regional Savannah area including the surficial, upper Brunswick, and upper Floridan. The unconfined surficial aquifer is generally within the upper 65 feet of consolidated and unconsolidated soils and primarily in 10 to 40 feet of sand. This zone is primarily used for residential and business irrigation. The clay Hawthorn Formation acts as an aquitard separating the surficial aquifer and the upper Brunswick aquifer. The upper Brunswick aquifer is used primarily for industrial water uses within the Savannah area. The upper Brunswick is underlain by the upper Floridian aquifer which is composed of limestone with high water volume extraction potential and is the primary source for community water supply wells and significant industrial water needs.

The surficial aquifer at the Site is composed of two prominent water bearing units. The UWBZ is a shallow water bearing zone within the upper 10 to 12 feet of subsurface material generally consisting of silty sand. Beneath the UWBZ is an approximately 20-foot layer of sandy silt and clay of much lower permeability (native marsh sediment), which acts as an intermediate aquitard.

The LWBZ lies beneath the native marsh sediment and consists of silty, clayey sand of varying thickness from 9 to 15 feet. Except for minor fluctuations localized to shoreline areas, groundwater levels in the UWBZ are not influenced by tidal changes in the Savannah River, while groundwater levels in the LWBZ are tidally influenced, with the degree of tidally induced fluctuation decreasing with distance from the shoreline.

4.2.1 UWBZ Groundwater Levels and Flow Direction

Based on a review of the RFI and PPCAP data, the groundwater levels in the UWBZ range from 2.78 to 14.65 feet above mean sea level (MSL) in the vicinity of the TiO_2 Plant and from 1.29 to 18.99 feet above MSL at the Deptford Tract. Groundwater levels at MSL occur in the Saltwater Mitigation Bank area to the west of Fort Jackson and in the tidally-influenced marsh area from the southeastern perimeter of the industrial areas southward to Elba Island Road and the Wilmington River. A groundwater divide is aligned with the axis of the developed portion of the peninsula and defines a zone of divergent groundwater flow toward the groundwater discharge zones located along the shoreline.

Groundwater flow in the UWBZ is generally to the northwest toward the Savannah River and to the southeast and east toward the Wilmington River. Groundwater levels in the UWBZ generally mimic topography. In addition to the principal divide along the peninsula axis, local divides exist where the ground surface is elevated. At the TiO_2 main plant, local groundwater mounds occur beneath the TiO_2 settling ponds located on the eastern side of the plant and the pond dredge spoil area located in the vicinity of monitoring well MPW-17A. Groundwater levels are also elevated beneath the gypsum piles located in the vicinity of the Gypsum Plant. As noted previously, the UWBZ is insensitive to tidal fluctuations in the Savannah River.

4.2.2 LWBZ Water Levels and Flow Direction

Average groundwater levels in the LWBZ range from -0.44 to 3.15 feet MSL in the vicinity of the TiO_2 Plant and from 0.31 to 8.73 feet above MSL at the Deptford Tract. An area of low groundwater levels west of Fort Jackson in the Saltwater Mitigation Bank area generally aligns with the groundwater low observed in the UWBZ. This low is likely a saltmarsh area in direct communication with the river. In addition, low groundwater levels are assumed for the tidally-influenced area comprising the southeast portion of the property. As was noted for the UWBZ, a groundwater divide is aligned with the axis of the peninsula along which flow is either northwestward toward the Savannah River or southeastward and eastward toward the Wilmington River. The maximum groundwater levels in the LWBZ coincide with the wastewater settling ponds located in the eastern portion of the TiO_2 Plant. As discussed, LWBZ gradients and flow directions will vary with the tide.

5.0 MONITORING WELL LOCATIONS

During the RFI there were forty-eight (48) temporary or permanent UWBZ wells installed and twenty-six (26) temporary or permanent LWBZ wells installed. Data obtained from the sampling and analysis of the groundwater in these wells were evaluated in the human health risk assessment to determine the COCs and their potential risk to human receptors.

Forty-two (42) UWBZ wells, including nine (9) existing wells and thirty-three (33) new wells, and thirty-seven (37) LWBZ wells, including eight (8) existing wells and twenty-nine (29) new wells, are proposed for this GMP. In addition, one (1) land use control groundwater monitoring well (LUC-1) will be installed in the LWBZ. Four (4) existing wells (MPPZ-02A, MPW-07A, M-2B, and MPPZ-02B) are anticipated to be lost due to proposed excavation and dredging activities and will be relocated and designated as replacement wells (MPPZ-02AR, MPW-07AR, M-2BR, and MPPZ-02BR). See Figure 2, 3, and 4 of Appendix A for the location of the existing and proposed wells. See Tables 2 and 3 in Appendix B for specific well location and elevation data information on existing wells. Upon approval of this GWP and prior to initiating the semi-annual sampling activities, a professional geologist or engineer registered in the State of Georgia will inspect and certify the integrity of each existing monitoring well in accordance with the Water Well Standards Act.

Remedy effectiveness monitoring will be completed at thirty-eight (38) UWBZ/LWBZ well locations surrounding the Waste Containment Area [Dredged Spoil Area-Filter Press Area, Geotube Area, Pond Spoil Piles, Inactive Pond (IP) Area-Ponds 1, 2, 3, and 4 (EU11), Active Pond (AP) Area-Ponds 5 and 6 (EU10)]. These wells are designated as UWBZ wells MPPZ-02AR, MPPZ-03A, MPW-03A, MPW-07AR, MPW-09A, MPW-21A, WCAMW-1A, WCAMW-2A, WCAMW-3A, WCAMW-4A, WCAMW-5A, WCAMW-6A, WCAMW-7A, WCAMW-8A, WCAMW-9A, WCAMW-10A, WCAMW-11A, WCAMW-12A, WCAMW-13A, and WCAMW-14A; and LWBZ wells M-2BR, MPPZ-02BR, MPW-03B, MPW-07B, MPPZ-03B, MPW-21B, WCAMW-1B, WCAMW-2B, WCAMW-3B, WCAMW-4B, WCAMW-5B, WCAMW-6B, WCAMW-7B, WCAMW-8B, WCAMW-9B, WCAMW-10B, WCAMW-11B, and WCAMW-12B.

Effectiveness monitoring will be completed at fifteen (15) UWBZ/LWBZ well locations surrounding the Developed Area (EUs 05, 06, 09, 12, 13, and 14). These wells are designated as UWBZ wells MPPZ-01A, MPW-01A, MPW-04A, MPW-18A; DAMW-01A, DAMW-02A, DAMW-03A, DAMW-04A, and DAMW-05A; and LWBZ wells include MPPZ-01B, MPW-01B, MPW-04B, MPW-18B, DAMW-01B, and DAMW-05B.

Effectiveness monitoring will be completed at twenty-six (26) UWBZ/LWBZ well locations surrounding the Gypsum Area (EU02 and 03) and the former Municipal Solid Waste Incinerator (EU06). These wells are designated as UWBZ wells PMW-17, GWMW-1A, GWMW-2A, GWMW-3A, GWMW-4A, GWMW-5A, GWMW-6A, GWMW-7A, GWMW-8A, GWMW-9A, GWMW-10A, GWMW-11A, and GWMW-12A; and LWBZ wells MW-19B, GWMW-1B, GWMW-2B, GWMW-3B, GWMW-4B, GWMW-5B, GWMW-6B, GWMW-7B, GWMW-8B, GWMW-9B, GWMW-10B, GWMW-11B, and GWMW-12B.

6.0 MONITORING WELL DESIGN AND CONSTRUCTION

All monitoring wells shall be installed under the supervision of a geologist or engineer who is registered in the State of Georgia and who will certify to EPD the monitoring well installation complies with the Rules for Solid Waste Management *Manual for Groundwater Monitoring*. A State of Georgia registered geologist or engineer will also certify the wells are installed pursuant to this GMP. All monitoring wells shall be designed, installed, and developed in accordance with Georgia Water Well Standards Act (OCGA 12-5-120) and EPA Region 4 Science and Ecosystem Support Division (SESD) Guidance document *Design and Installation of Monitoring Wells*, SESDGUID-101-R1, effective date January 29, 2013. The driller must maintain a current State of Georgia Water Well Driller's Bond.

7.0 DRILLING METHODS

A variety of well drilling methods are available for the purpose of installing groundwater monitoring wells. The drilling method shall minimize the disturbance of subsurface materials and shall not cause contamination of the groundwater. Regardless of the drilling method selected, drilling equipment shall be steam cleaned before use and between borehole locations to prevent cross contamination of wells. To further control cross-contamination, the clean upgradient wells should be installed first, and downgradient wells of most likely COC flow directions should be installed last. This Site will employ the hollow-stem continuous auger drilling method or other methods based on site conditions.

8.0 MONITORING WELL CONSTRUCTION AND MATERIALS

Well construction materials shall be sufficiently durable to resist chemical and physical degradation and yet not interfere with the quality of groundwater samples. Materials to be used for well casings, well screens, filter packs, and annular seals are covered in this section.

Well depth will be governed by the depth to groundwater and will be determined in the field as drilling progresses. Ideally monitoring well screens should be installed to intersect the water table; but existing conditions may warrant otherwise (e.g., significantly higher than normal water-table elevations or permanently shallow groundwater). Moreover, setting a well so that the entire sand filter pack is below the water-table facilitates well development and insures that the monitoring well will not go dry. If shallow groundwater is encountered such that there is insufficient linear footage for the installation of a proper annular seal, screens will be set below the water-table; but as close to the water-table as possible without jeopardizing the integrity of the annular seal. In general, however, the well depths will be extended to approximately 10 feet below the water-table potentiometric surface.

8.1 Well Casings and Screens

ASTM International (ASTM), National Sanitation Foundation (NSF) rated, Schedule 40, two (2) inch polyvinyl chloride (PVC) shall be used for the casing pipe and well screens at the Site. The screen length for each well shall be ten (10) feet, unless ample justification is given by the geologist/engineer to use a different screen length. It is understood that since PVC pipe is being selected for casing and screening material there may be the possibility that after installation PVC deteriorating compounds could be present in the groundwater. If these compounds are detected, then EPD must assume that the contaminants are from the Site and not from the well casing or screen, unless identical compounds are found in the upgradient wells and cannot be attributed to wastes placed in the Site.

Plastic pipe sections must be flush threaded or be amenable to connection by other mechanical methods such as stainless-steel screws. No solvents or glues should be allowed in well construction. All well casings and screws should be steam cleaned prior to emplacement to ensure that all oils, greases, and waxes have been removed.

As with drilling machinery, the well casing and screen shall be decontaminated before use. Filter sands, well sealant materials, and anything else that may influence sample quality shall be free of contamination. Samples of filter sands, well sealant materials, well casing and screen shall be saved from each well for a period of one (1) year for future analysis, if necessary.

8.2 Filter Pack and Annular Sealant

The materials used to construct the filter pack shall be chemically inert, clean quartz sand. The filter pack will be based on the formation grain size in order to try and match the existing grain size. Sieve analysis for filter pack will be submitted along with the well documentation report. Fabric filters shall not be used as filter pack materials. The materials used to seal the annular space must prevent cross contamination between strata. The materials shall be chemically resistant to ensure seal integrity during the life of the monitoring well and chemically inert so they do not affect the quality of the groundwater samples.

A minimum of two (2) feet of certified coarse grit sodium bentonite shall immediately overlie the filter pack. Dry bentonite chips or pellets overlying the filter pack shall be hydrated once placed in the well's annular space. Bentonite chips or pellets will be hydrated in accordance with the specific manufacturer's recommendations. A cement and bentonite mixture, bentonite chips/pellets, or anti-shrink cement mixtures shall be used as the annular sealant in the vadose zone above the certified coarse grit sodium bentonite seal and below the frost line.

Extending from below the frost line to the surface, the cap shall be composed of a continuously poured concrete collar and cement apron sloping 1/4-inch per horizontal foot from the well casing and having a minimum 2-foot by 2-foot by 4-inch concrete surface pad completion.

The untreated sodium bentonite seal shall be placed around the casing either by pouring it under the influence of gravity directly down the borehole or, if a hollow-stem auger is used, pouring the bentonite between the casing and the inside of the auger stem. Both of these methods present a potential for bridging between the well stem and hollow-stem auger. In shallow monitoring wells, a tamping device shall be used to reduce this potential. In deeper wells, it may be necessary to pour a small amount of formation water down the casing to wash the bentonite down the hole.

The cement-bentonite mixture shall be prepared using potable water and placed in the borehole using a tremie pipe. The tremie method ensures good sealing of the borehole from the bottom. The remaining annular space shall be sealed with expanding cement to provide for a well collar ensuring security and an adequate surface seal. Locating the interface between the cement and bentonite-cement mixture, with bentonite mixed with up to 5 percent by weight, 1/2 to one (1) foot below the frost line serves to protect the well apron and collar from damage due to frost heaving. The cement shall be placed in the borehole using the tremie method.

8.3 Protective Cover and Sump

An appropriate protective steel cover (4-inch x 4-inch x 4-feet) is required to be placed around the well casing. A 1/4-inch vent hole provides an avenue for the escape of gas. A 1/4-inch weep hole shall also be drilled through the protective cover (and not the PVC riser pipe) at the base of the protective cover to allow for drainage of the annular space. The protective cover guards the casing from damage and the locking cap serves as a security device to prevent well tampering. A 6-inch threaded end cap "sump" will be threaded to the bottom of each screen to serve as a sediment trap. Additionally, pea gravel will be placed between the PVC riser and the steel cover. Each protective well cover will have a 2-foot by 2-foot by 4-inch concrete surface pad completion, as previously discussed.

8.4 Well Intake Design

The design and construction of the intake of the monitoring wells shall 1) allow sufficient groundwater flow to the well for sampling; 2) minimize the passage of formation materials (turbidity) into the well; and 3) ensure sufficient structural integrity to prevent the collapse of the intake structure.

For wells completed in unconsolidated materials, the intake of a monitoring well shall consist of a screen or slotted casing with openings sized to ensure that formation material is prohibited from passing through the well during development. Screen size shall be selected to retain 90% of the filter pack and 40% of the formation material. Extraneous fine-grained material (clays and silts) that have been dislodged during drilling may be left on the screen, in the filter pack, and in the well water. These fines shall be removed from the screen and surrounding area during development. For quality-control purposes, only commercially manufactured screens or slotted casings shall be used. Screening with 0.010-inch slots shall be used. Field slotting of screens is unacceptable.

The annular space between the face of the formation and the screen or slotted casing shall be filled to minimize passage of formation materials into the well. The owner/operator shall install a filter pack of clean, well-rounded quartz sand in each monitoring well that is constructed on-site. The filter pack will be designed following the procedures specified in USEPA's (former) SESD guidance number SESDGUID-101-R1, entitled "*Design and Installation of Monitoring Wells*". In addition, the neat cement grout and cement / bentonite grout will have to be prepared according to Section 2.3.5 of Laboratory Services and Applied Sciences Divisions (LSASD) guidance SESDGUID-101-R1. To ensure discrete sample horizons, the filter pack shall extend no more than two (2) feet above the well screen as illustrated in Figure 5. A different filter pack material may have to be considered should geologic conditions at the time of drilling dictate the need for a different size material.

8.5 Well Development

After the construction of monitoring wells is completed each well shall be developed to restore the natural hydraulic conductivity of the formation and to remove all foreign sediment to ensure turbidity-free groundwater samples in accordance with EPA Region 4 SESD Guidance document *Design and Installation of Monitoring Wells*, SESDGUID-101-R1, effective date January 29, 2013. The first method of choice for the development of the wells will be the bail-and-surge technique. Non-dedicated disposable polyethylene bailers, with additional weights for ballast, and nylon ropes will be used for well evacuation; and a sand-filled 5-foot PVC slug (1.5-inch nominal diameter) with a nylon rope will be used for surging. Alternately, a reusable, heavy bailer may be used to accomplish both bailing and surging. If deemed necessary, alternative procedures in accordance with SESDGUID-101-R1 may be selected for the development of the wells.

All dedicated equipment used to develop a well will be cleaned prior to its introduction into the well. The cleaning method will consist of a potable water and laboratory-grade detergent wash, then a rinse, and, finally, a deionized water rinse; and/or steam cleaning will be used where appropriate. Once the gross particulate matter has been eliminated from the wells, the turbidity of the well water will be measured.

In accordance with SESDGUID-101-R1, a newly completed monitoring well should not be developed for at least 24 hours after the surface pad and outer protective casing are installed. A new monitoring well should be developed until the column of water in the well is free of visible sediment and the pH, temperature, turbidity, and specific conductivity have stabilized in accordance to the criteria in Table 4 of Appendix B. If during subsequent sampling events turbidity of less than 10 NTUs is not achieved, redevelopment of the monitoring wells will be required or alternative methods will be implemented to achieve turbidity levels less than 10 NTUs.

8.6 Documentation of Well Design and Construction

The following information shall be required in the design and construction of wells:

- Name of driller and license number;
- The driller's bond on file with the Water Well Advisory Council;
- Identification of drill rig;
- Date/time of construction;
- Drilling method and drilling fluid (primarily drilling mud) used;
- Well location (± 0.5 feet);
- Borehole diameter and well casing diameter;
- Well depth (± 0.1 feet);
- Drilling and lithologic logs;
- Casing materials;
- Screen materials and design;
- Casing and screen joint type;
- Screen slot size/length;
- Filter pack materials/size, filter pack volume;
- Filter pack placement method;
- Sealant materials, sealant volume, and seal design;
- Sealant placement method;
- Well development procedure;
- Surface seal design;

- Type of protective well cap;
- Survey the location (Georgia State Plane East NAD83) and elevation (NAVD88) of monitoring well components:
    - Ground surface elevation (± 0.01 feet);
    - Well cap elevation (± 0.01 feet);
    - Top of casing elevation (± 0.01 feet);
    - Detailed drawing of well (include dimensions);
- Well installation certification signed and sealed by a Georgia-registered professional engineer/geologist;
- Certification of the survey data signed and sealed by a Georgia-registered Land Surveyor; and
- Supporting documentation associated with the selection of the filter pack (e.g., grain size curves, etc.).

Samples of materials, adequate for leaching/sorption tests should be retained. The geologist or engineer registered in the State of Georgia will submit in report form to EPD the documentation for the construction of each well within 30 days after development of the wells.

8.7 Well Abandonment

If during the life of the groundwater monitoring program abandonment of a groundwater monitoring well is necessary, the abandonment procedures shall be in accordance with the Georgia Water Well Standards OCGA 12-5-134 *Standards for wells and boreholes*, SESDGUID-101-R1, effective date January 29, 2013. Per Rule 391-3-4-.14(10)(b), monitoring wells require replacement after two (2) dry sampling events, unless an alternate schedule has been approved by the Division. The following well abandonment procedures will be used:

1. If possible/practical, removal of the well casing, sealant material, and filter pack by reaming out the borehole using the hollow-stem auger method (as a minimum when the casing is not properly grouted, the upper 20 feet of casing should be removed), and then plugging of the well or borehole with an impermeable material such as 3- to 5-weight-percent-bentonite cement grout or straight bentonite clay pellets/chips.
2. Alternately, if the well is judged to have a competent annular seal that makes overdrilling impossible, the well casing will be filled and plugged with an impermeable material.

    Once the well is completely filled, plugged, and sealed, the wellhead should be removed as part of the well abandonment process. If grout is used to plug the well, it will be placed by tremie pipe so that the well is filled upward from the bottom. If bentonite clay is used separately, the pellets or chips will be dropped directly down the well; a tamping device will be used to prevent bridging. While filling the well with granular bentonite, slugs of potable water will be poured down the well in several stages to ensure proper hydration of bentonite clay.

3. The abandonment of all borings/piezometers/monitoring wells shall be supervised by a professional geologist or professional engineer registered to practice in the State of Georgia. A report documenting the abandonment shall be submitted to EPD. This documentation shall be signed and stamped by the responsible professional geologist or engineer registered to practice in the State of Georgia.

Estimated well sealant volumes in the event of well abandonment activities are presented in Table 5 of Appendix B.

8.8 Sealant Materials for Well Abandonment

Well sealant shall be chemically inert and impermeable. Neat portland cement (with or without bentonite clay additives) and bentonite clay are acceptable sealants. General purpose (Type 1) neat portland cement is acceptable. The cement slurry is to be mixed with five (5) to six (6) gallons of water for each 94-pound sack of cement. The water of the cement slurry should have a low sulfate content and a total dissolved solids content less than 2,000 parts per million. No aggregate materials are to be included in the slurry. Recommended quantities of neat portland cement needed for plugging various diameter wells as shown in Table 5 of Appendix B.

Quantities are based on the set volume, which is somewhat less than the slurry volume (taken from "*Plugging Abandoned Wells*" by Donald K. Keech, Ground Water Age, January 1973). The neat cement slurry shall be pumped to the point of application so that the well is filled upward from the bottom. Free falling of the slurry into the well is unacceptable because the cement will become aerated with a resulting increase in permeability. Also, when cement comes in to contact with water it tends to separate. Therefore, cement should be piped into place to avoid separation.

Three (3) to five (5) pounds of additive and 6.5 gallons of water shall be mixed with each 94-pound sack of cement (the clay and water are to be mixed together before cement is added to form the slurry). Bentonite clay can be used separately as a well sealant. The clay can be dropped into the well in the form of granules, chunks, pellets, or bails. Where the potentiometric head of an aquifer causes water to rise in the well high above the level of the plug, consideration must be given to the physical form of the bentonite to be used. If a granular bentonite is added by free falling, a possibility is that the clay will hydrate and expand above the intended point of placement. In this situation, an ineffective plug will result. Adding the bentonite in chunk or pellet form will prolong the effective period of wetting prior to hydration and allow proper placement of the plug. Bentonite clay cannot be used as a sealant where organic contaminants are present in groundwater unless the bentonite is treated and documentation is presented to show that it is capable of containing organic contaminants.

Shallow monitoring wells installed in unconsolidated sediments are to be filled with a sealant. Backfilling of the screened or uncased section of the well (up to several feet below the casing) with clean, disinfected sand is permissible. Sand with a diameter of 0.025 inches or less (plaster sand or mortar sand) reduces cement penetration/loss. As a minimum, the upper 50 feet of deep monitoring wells shall be plugged with neat cement or bentonite clay. Sand and clay fill materials are not suitable because the fine-grained sediments can be eroded away by groundwater flow. The use of bridging materials, such as pea gravel or larger rocks (the diameter of the bridging material should be less than 1/3 of the diameter of the well), below the casing or the placement of a plug at the base of the casing may be necessary to retain the neat portland cement slurry in the well. Where several confined aquifers are present in an abandoned monitoring well, impermeable seals between water bearing sections are required. Flow from artesian wells can cause problems with the installation of neat portland cement. Packers or heavy plugs shall be required to inhibit water flow between confined aquifers.

8.9 Monitoring Well Installation Depths

Each proposed groundwater monitoring well and well screen is expected to be installed to the depths consistent with the existing UWBZ and LWBZ wells presented in the Table 2 and 3 of Appendix B based on the geologic conditions for this Site as described in the following report and revisions:

- *Prospective Purchaser Corrective Action Plan* (PPCAP), approved by the Georgia Environmental Protection Division on July 19, 2017 (Tetra Tech)

However, the final well depth and screen elevation will be based on field conditions at the time of drilling. Conditions encountered during well installation may warrant variation of the depths of the existing UWBZ and LWBZ wells presented in Table 2 and 3 of Appendix B. If such conditions arise, the Site owner or their delegated consultant are to be notified immediately, and such conditions should be discussed in the well installation report.

8.10 Signage

A well ID marker shall be installed adjacent to each groundwater monitoring point.

A well installation report will be submitted following the completion of all well installation activities.

9.0 SAMPLE COLLECTION FREQUENCY AND REPORTING

9.1 Data and Sample Collection Guidance Documents

Field and water quality data will be collected in accordance with the most recent available versions of the following USEPA Region 4 SESD/LSAS Operating Procedure and Guidance documents:

- *Groundwater Level and Well Depth*, LSASDPROC-105-R4, effective date May 15, 2020;
- *Field pH Measurement*, SESDPROC-100-R4, effective date December 16, 2016;
- *Field Specific Conductance Measurement*, LSASDPROC-101-R7, effective date May 5, 2020;
- *Field Temperature Measurement*, SESDPROC-102-R5, effective date March 14, 2018;
- *Field Turbidity Measurement*, SESDPROC-103-R4, effective date July 27, 2017;
- *Groundwater Sampling*, SESDPROC-301-R4, effective date April 26, 2017;
- *Design and Installation of Monitoring Wells*, SESDGUID-101-R1, effective date January 29, 2013; and
- *Decontamination Procedures / Field Equipment Cleaning and Decontamination, LSASDPROC-205-R4, effective date June 22, 2020.*

9.2 Frequency and Parameters

The groundwater monitoring wells will be sampled in accordance with this GMP. Sampling events will be initiated within six (6) months after receiving well construction approval from EPD.

Monitoring only groundwater parameter data will be evaluated to determine the effectiveness of the hot spot removal and waste containment remedial activities completed at the site. Monitoring only parameters identified in Table 1 will be analyzed in accordance with PPCAP Table 2-23 but do not have established groundwater cleanup goals. Discussions regarding the presence or absence of these constituents in groundwater, as well as their concentrations trends will be presented in the Groundwater Monitoring Reports. The wells in the groundwater monitoring network (including well LUC-1) will be routinely sampled semiannually for the analytes listed in Table 1, unless otherwise stated in this document.

It should be noted that the analytical suites performed for the groundwater samples include additional analytes that have no cleanup goals and are not required for monitoring per the PPCAP. The results for these compounds will be included for review in the supporting laboratory analytical reports.

Land Use Control groundwater monitoring well (LUC-1) will be sampled and analyzed for the following: dioxins/furans by EPA methods 613, 8280, and 8290; inorganic constituents by EPA methods 6010, 7040, 7041, and 7196A; semi-volatile organic constituents by EPA method 8270; volatile organic constituents by EPA method 8260; and polychlorinated biphenyls by EPA method 8082a.

After three years of semiannual sampling for all the Table 1 constituents, a petition (including adequate supporting documentation) may be submitted to EPD requesting that the sampling frequency be changed to annual. If at some point in time, monitoring is not necessary and/or required, sampling will be terminated with EPD approval.

Sampling events for dioxins and furans will be completed in accordance with the following:

- Year 1 – Two semiannual sampling events for dioxins / furans analysis. Sample well LUC-1, and all the wells in the waste containment area, developed area, and Exposure Unit (EU) 6 – Waste Incinerator Area. Then, evaluate the dioxins profile associated with each well according to the methodology described in the facility's RCRA Facility Investigation.
- Years 2 and 3 – Annual sampling events for dioxins / furans analysis. Sample only those wells that in Year 1 had concentrations of dioxins / furans above the laboratory reporting limits and exhibited a site-related dioxins profile (i.e., chloride profile, waste incineration profile).
- Year 4 – Annual sampling event for dioxins / furans analysis. Sample well LUC-1, and all the wells in the waste containment area, developed area, and EU 6 – Waste Incinerator Area. Then, similarly to Year 1, evaluate the dioxins profile associated with each well.
- Years 5 and 6 – Annual sampling events for dioxins / furans analysis. Based on the findings of Year 4, sample only those wells that had concentrations of dioxins / furans above the laboratory reporting limits and exhibited a site-related dioxins profile (i.e., chloride profile, waste incineration profile).

After completion of the sixth year of monitoring, the data may be evaluated to prepare a new monitoring scheme. During this time, or in the event that a new monitoring scheme for dioxins / furans is not pursued, the groundwater monitoring program for these constituents will continue as follows:

- Semiannual sampling (or other frequency agreed by EPD) of those monitoring wells that had: 1) concentrations of dioxins / furans above the laboratory reporting limits, and 2) a site-related dioxins profile (i.e., chloride profile, waste incineration profile); and,
- Once every five years, well LUC-1 and all the wells in the waste containment area, developed area, and EU 6 – Waste Incinerator Area will have to be sampled to: 1) assess

the spatial distribution of site-related dioxins / furans in groundwater, and 2) update the subset of wells that are sampled more frequently, as described above.

If a new monitoring strategy is sought, following the first 6 years of groundwater sampling, a petition including adequate supporting documentation may be submitted to EPD requesting annual groundwater sampling frequency and a reduction in the number of analytes for which monitoring is required to include monitoring for dioxins and furans.

Groundwater sampling will be generally consistent with applicable components of the Closure Criteria (391-3-4-.11) and Post-Closure Care Solid Waste Management Rules (391-3-4-.12). The parameters requiring monitoring but not requiring reporting shown in Table 1 will only be analyzed annually.

Groundwater monitoring well samples shall be collected in accordance with the parameters and methods presented in Table 1 of Appendix B unless otherwise stated above.

10.0 GENERAL FIELD SAMPLING PROCEDURES

The groundwater monitoring program involves collecting groundwater level measurements from the designated wells and collecting groundwater samples from the designated wells. This section presents the specific procedures for performing these activities, including:

- Field measurement procedures and criteria;
- Sampling methods;
- Quality control sample protocols;
- Sample container requirements;
- Sample preservation methods;
- Decontamination procedures; and
- Documentation of sampling activities.

This section is intended to be a field manual and provides field personnel with easy-to-use procedures and methods for consistently collecting quality, representative groundwater samples and measurements. Field personnel must understand and use these field sampling procedures (FSPs) during groundwater sampling events, consistently follow the specified procedures and protocols, and clearly document deviations from the FSPs, along with reasons for deviations.

10.1 Groundwater Level Measuring

Water level elevations shall be measured on a continuing basis to determine if horizontal and vertical flow gradients have changed since the initial Site characterization. A change in hydrologic conditions may necessitate modification to the design of the groundwater monitoring system. Field measurements shall include depth to standing water and total depth of the well to the bottom of the intake screen structure in accordance with *Groundwater level and Well Depth,* LSASDPROC-105-R4, effective date May 15, 2020.

Groundwater level measurements will be collected from all monitoring wells at the beginning of each monitoring event, and prior to sampling. Tabulated water level measurements should be collected within 24 hours. Tidally-influence LWBZ monitoring wells shall be taken within a short timeframe of less than 2 hours bracketing high or low tides. Groundwater levels shall be measured to the nearest 0.01 foot, from their respective well reference points (i.e., the top of the inner casing in relation to a permanent benchmark) and the survey shall also note the well location and top of casing elevation. Groundwater level measurements will be compared to the most recent measurements obtained for that well. If the measurements differ by more than 0.5-foot, a second groundwater level measurement will be collected for verification purposes.

Groundwater levels shall be measured using a decontaminated water level indicator. The water level indicator used to measure the depth to water in the monitoring wells will be decontaminated according to *Decontamination Procedures / Field Equipment Cleaning and Decontamination*, LSASDPROC-205-R4, dated June 2, 2020. If multiple meters are used, the calibration of each meter is checked for accuracy. The following procedures are followed each time water levels are measured in a monitoring well:

1. Turn on water level meter. Depending on the condition of the water level meter, the sensitivity may have to be adjusted by turning the power switch dial to the desired sensitivity level. Typically, the water level meter works best adjusted to a low sensitivity.
2. Press the appropriate button to test the meter.
3. Clean the meter and/or confirm that the meter has been properly decontaminated.
4. Open/unlock well head.
5. Don a new pair of nitrile gloves.
6. Water level readings are measured relative to the surveyed mark on the top of the well’s inner casing. If a mark is not present, measure from the northernmost top of well casing.
7. Lower the water level meter probe into the well. When the buzzer sounds, and/or the light turns on, stop the probe’s descent. Gently raise the probe until the buzzing stops. Gently lower the probe until the buzzing starts again and stop. The cable should be immediately

next to the measuring mark from now until the final reading is measured. If the buzzer stays on, or is very weak, adjust the sensitivity.

8. Without changing the hold on the cable, raise the probe out of the water and retest the measurement.
9. Keep adjusting the hand location until two identical readings are noted. Identical readings will be the same to 0.01 of a foot.
10. If the numbers on the cable can be observed, read the measurement at the mark to the nearest 0.01 foot.
11. If the numbers on the cable cannot be observed, place fingers around the cable at the location where the buzzer sounds relative to the reference point, pull the cable out without moving your hand with respect to its location on the cable, and record the reading.
12. If the two readings are within 0.01 foot, record the depth to water reading on the appropriate form.
13. Remove the probe from the well. Take note where the cable becomes wet. The cable and probe below this point needs to be decontaminated.
14. Decontaminate the probe and two feet (or the appropriate length if more than two feet immersed in water column) of cable by immersing in an Alconox® solution followed by immersing in tap water and deionized water rinses, respectively.
15. Spool the remaining cable.
16. Secure the probe in the holder.
17. Turn off water level meter.
18. Commence sample collection procedures or close and lock the well.

Total well depth will be measured in accordance with Groundwater Level and Well Depth Measurement, LSASDPROC-105-R4, effective date May 15, 2020. The electronic water level indicator will be utilized to measure total well depth. The tape or cable will be lowered until the weighted end is felt resting on the bottom of the well. It is acceptable to lower the tape or cable to the bottom of the well allowing the tape or cable to touch bottom then to detect the “tug” on the tape while lifting the weight off the well bottom. Total depth measurements will be recorded to the nearest 0.1 foot.

10.2 Groundwater Quality Monitoring

Groundwater quality monitoring includes field and laboratory analyses. Only meters that are calibrated at the beginning of the work day shall be used to measure field water quality parameters, which include temperature, pH, turbidity, and specific conductance (SC). Field water quality parameters are measured in a flow-through cell at regular intervals (typically every five minutes) during the low-flow process.

As part of the monitoring report groundwater quality parameters will be submitted including: pH, temperature, turbidity, specific conductance, and the static water levels of the wells. The water quality and water level data shall be sampled/collected in accordance with the following EPA Region 4 SESD/LSAS Operating Procedures.

- *Field pH Measurement*, LSASDPROC-100-R5, effective date July 23, 2020;
- *Field Specific Conductance Measurement*, LSASDPROC-101-R7, effective date May 5, 2020;
- *Field Temperature Measurement*, SESDPROC-102-R5, effective date March 14, 2018;
- *Field Turbidity Measurement,* SESDPROC-103-R4, effective date July 27, 2017*;*
- *Field Measurement of Dissolved Oxygen*, SESDPROC-106-R4, effective date April 12, 2017.
- *Field Measurement of Oxidation-Reduction Potential (ORP)*, SESDPROC-113-R2, effective date April 26, 2017.

10.2.1 Field Parameter Measurements and Stabilization

Monitoring wells shall be sampled in general accordance with the EPA Region 4 SESD operating procedure titled "*Groundwater Sampling*", SESDPROC-301-R4, effective date April 26, 2017. Field water quality data are recorded during well purging to determine when groundwater conditions in the well have stabilized, and representative formation water is being sampled.

Conditions of pumping during purging will be performed in general accordance with SESDPROC-301-R4. Prior to initiating pumping a properly decontaminated well sounder or electronic water level meter will be lowered into the well to measure the water level prior to and during the purging process. Excessive pump rates and drawdown can result in increased turbidity or aeration of the sample. Pumping rates between 100 – 200 mL/min should be maintained and a stable drawdown (an unchanging water level) should be achieved.

As stated above, field parameters are measured in a flow-through cell at regular intervals (typically every five minutes) during the low-flow purging process, and purging continues until the field parameters have stabilized based on the criteria summarized in Table 4 of Appendix B. Stabilization occurs when, for at least three consecutive measurements, pH remains constant within 0.1 Standard Unit (SU), specific conductance varies no more than approximately 5 percent, turbidity is less than 10 Nephelometric Turbidity Units (NTUs) in accordance with *Groundwater Sampling*, SESDPROC-301-R4, effective date April 26, 2017. In addition, stabilization of the well purge will also be indicated by field parameters showing no increasing or decreasing trends for three successive readings.

Other parameters, such as dissolved oxygen (DO) or oxidation-reduction potential (ORP), may also be used as a purge adequacy parameter. Normal stability goals for DO are 0.2 milligrams per liter (mg/L) or 10% change in saturation, whichever is greater in accordance with *Field Measurement of Dissolved Oxygen*, SESDPROC-106-R4, effective date April 12, 2017. DO and ORP measurements must be conducted using either a flow-through cell or an over-topping cell to minimize oxygenation of the sample during measurement. A reasonable ORP stability goal is a range of 20 millivolts (mV). The stabilization criteria shall also be listed on the field well sampling forms.

Field parameter stabilization criteria and goals for monitoring well purging and sampling are summarized and presented in Table 4 of Appendix B.

10.2.2 Groundwater Sample Collection Procedures

The goal of groundwater sampling is to collect samples that are representative of in-situ groundwater conditions and to minimize changes in groundwater chemistry that would adversely affect analyte concentrations during sample collection and handling. To achieve this goal, groundwater samples shall be collected from the monitoring wells using EPA's Low Stress (low-flow) *Purging and Sampling Procedure for the Collection of Groundwater Samples from Monitoring Wells* SESDPROC-301-R4 and summarized below.

Beginning with upgradient wells first and progressing sequentially through wells with the lowest to highest contaminant concentrations, groundwater conditions are stabilized, and samples collected in a consistent manner for each well. A variable speed peristaltic pump is to be used to purge and collect groundwater samples from each well. Additionally, use of a bladder pump for groundwater purging and sampling is acceptable.

The following procedures will be used to collect groundwater samples from monitoring wells using the low-flow, minimal drawdown method by a peristaltic pump:

1. Arrive at well location and start to fill out Well Sampling Record. Fill out: Date, Time, Well ID, and Sampler.
2. Put on new nitrile gloves.
3. Using a decontaminated water level meter, measure and record the depth to water from the measuring point to an accuracy of 0.01 foot. The measuring point is marked on the top of the inner casing.

4. Feed the dedicated Teflon® or Teflon® lined tubing down to the sampling depth, which shall be the approximate mid-portion of the screened interval of the well, then connect the tubing to the peristaltic pump.
5. Verify that the control box is at the lowest setting and start the pump.
6. Adjust the setting on the control box to the point where water is produced from the well.
7. Measure and record the pumping rate in milliliters per minute (mL/min) by collecting the discharged water in a beaker or graduated cylinder. Adjust the controller setting as needed so that the flow rate is between 100 and 500 mL/min.
8. Once maximum discharge rate is achieved without lowering water level more than 0.3 feet, record the final purge settings on the Well Sampling Record for use in future sampling events. The purge time starts when the settings are adjusted.
9. Collect purge water into five-gallon plastic containers as needed.
10. Connect the discharge line to the flow-through cell.
11. After the flow-through cell is connected and air bubbles evacuated to the extent possible, water quality parameters (pH, specific conductance, temperature, and turbidity) and depth to water (DTW) are measured and recorded at approximate five-minute intervals. The relative percent difference (RPD) and delta calculations are conducted and recorded between the readings.
12. Continue to purge the monitoring well and record field parameters until three consecutive field measurements meet the criteria listed in Table 4.
13. Collect a groundwater sample following the sample collection procedures in Table 4.
14. Stop the pump. Disconnect the pump from the power source. If a generator is used, turn off the generator.
15. Place the sample bottles into a plastic bag and into a cooler with ice.
16. Disconnect the tubing from the peristaltic pump, secure the dedicated tubing in a clean, clearly labeled storage bag and secure the well cover. (The storage bag is placed in the on-site storeroom at the end of the day). Downhole equipment shall be decontaminated in general accordance with the procedures described in *Field Equipment Cleaning and Decontamination,* LSASDPROC-205-R4.
17. Pack up the equipment and mobilize to the next well.

The low-flow, minimal drawdown method by a peristaltic pump should be modified with the following procedures when using a vacuum transfer cap:

1. Disconnect the purge tubing from the pump. Make sure the tubing is securely attached to the protective casing or other secure object.

2. Insert the tubing into one of the ferrule nut fittings of a Teflon® vacuum container transfer cap assembly.
3. Place a suitable length of Teflon® tubing between the remaining transfer cap assembly ferrule nut fitting and the vacuum side of the flexible tubing in the peristaltic pump head. Securely hand-tighten both fittings.
4. Turn the pump on. Water will begin to transfer into the sample container within a few minutes, if it does not, check the transfer cap fittings and make sure the assembly is tightly attached to the container.
5. When the transfer container is nearly full, turn off the pump, remove the transfer cap assembly, and pour the sample into the appropriate containers.
6. If additional sample volume is needed, replace the transfer cap assembly, turn the pump on, and collect additional volume.

The following procedures will be used to collect groundwater samples from monitoring wells using the low-flow, minimal drawdown method by a bladder pump:

1. Arrive at well location and start to fill out Well Sampling Record. Fill out: Date, Time, Well ID, and Sampler.
2. Put on new nitrile gloves.
3. Using a decontaminated water level meter, measure and record the depth to water from the measuring point to an accuracy of 0.01 foot. The measuring point is marked on the top of the inner casing.
4. Connect a power source to the air compressor. A 12V compressor is typically utilized for low flow sampling to a maximum depth of 100 feet below ground surface.
5. Connect the compressor to a pump control and the pump control to the bladder pump using Teflon® or Teflon® lined tubing. Utilize a new disposable Teflon® bladder and tubing for collection of each sample. Connect an additional section of tubing from the bladder pump for use as a return flow.
6. Feed the bladder pump and dedicated tubing down to the sampling depth, which shall be the approximate mid-portion of the screened interval of the well, then connect the tubing to the bladder pump.
7. Verify that the pump control is at the lowest setting and start the pump.
8. Adjust the setting on the control box to the point where water is produced from the well.
9. Measure and record the pumping rate in milliliters per minute (mL/min) by collecting the discharged water in a beaker or graduated cylinder. Adjust the controller setting as needed so that the flow rate is between 100 and 500 mL/min.

10. Once maximum discharge rate is achieved without lowering water level more than 0.3 feet, record the final purge settings on the Well Sampling Record for use in future sampling events. The purge time starts when the settings are adjusted.
11. Collect purge water into five-gallon plastic containers as needed.
12. Connect the discharge line to the flow-through cell.
13. After the flow-through cell is connected and air bubbles evacuated to the extent possible, water quality parameters (pH, specific conductance, temperature, and turbidity) and DTW are measured and recorded at approximate five-minute intervals. The RPD and delta calculations are conducted and recorded between the readings.
14. Continue to purge the monitoring well and record field parameters until three consecutive field measurements meet the criteria listed in Table 4.
15. Collect a groundwater sample following the sample collection procedures in Section 10.2.3.
16. Stop the pump. Disconnect the pump from the power source. If a generator is used, turn off the generator.
17. Place the sample bottles into a plastic bag and into a cooler with ice.
18. Disconnect the tubing from the bladder pump, secure the dedicated tubing in a clean, clearly labeled storage bag and secure the well cover. (The storage bag is placed in the on-site storeroom at the end of the day).
19. Downhole equipment shall be decontaminated in general accordance with the procedures described in USEPA Region 4, SESD guidance document titled *Field Equipment Cleaning and Decontamination,* LSASDPROC-205-R4, effective date June 22, 2020.
20. Pack up the equipment and mobilize to the next well.

The purge rates for each well should be similar during successive sampling events. The purge rate for the low-flow method wells initially can be set to the rate used in previous events and adjusted as needed based on current groundwater conditions.

The following procedures will be used to determine total well depth using an electronic water level meter:

1. Arrive at well location.
2. Put on new nitrile gloves.
3. Using a decontaminated water level meter, lower the tape or cable to the bottom of the well.

4. Raise the tape or cable until the weight of the water level meter is felt indicating the water level tape or cable is not in contact with the well bottom. Record the total depth to an accuracy of 0.01 foot. The measuring point is marked on the top of the inner casing.
5. Repeat Step 4 until two consistent measurements to an accuracy of 0.01 foot are achieved.
6. Raise the tape or cable until the water level meter is removed from the well.
7. Downhole equipment shall be decontaminated in general accordance with the procedures described in USEPA Region 4 guidance document titled *Field Equipment Cleaning and Decontamination*, LSASDPROC-205-R4, effective date June 22, 2020.
8. Pack up the equipment and mobilize to the next well.

Additional sampling details (i.e., sample collection using vacuum transfer caps and soda straw method) are presented in Section 10.2.3.

10.2.3 Sample Collection Procedures for Laboratory Analysis

When the stabilization criteria are met, a groundwater sample shall be collected from each well in accordance with *Groundwater Sampling*, SESDPROC-301-R4. The sample containers for the more turbidity-sensitive analyses are filled first, as filling the VOC vials (and to a lesser extent the glass bottles) may disturb the well and increase turbidity. The most appropriate order of sampling with a peristaltic pump is generally to fill poly containers for metals and classical analyses, followed by glass bottles for SVOCs and associated analyses, and finally to fill 40 mL VOC vials.

Groundwater samples are collected from the pump discharge line directly into laboratory-supplied containers appropriate for the specific analysis being conducted. Specific procedures for collecting groundwater samples include the following:

1. Fill out the sample bottle labels using a pen with black waterproof ink. If sampling preservatives have not been previously added to the appropriate bottle(s) by the lab, place the preservative provided by the lab in the appropriate bottle(s).
2. Don new nitrile gloves.
3. Disconnect the pump's discharge line from the flow-through cell. When the well purge has been determined to be sufficient, fill containers for metals and classical analyses directly from the pump outlet. There is no need to interrupt pumping. The tubing should be held at the opening of the container and should not touch the container during filling. Protect caps from dust and debris during filling.
4. After filling the containers for metals and classical analyses stop the pump. Make sure that the tubing leading into the well is secured against movement during the following operations.

5. Samples for organic analyses cannot be exposed to the flexible peristaltic pump-head tubing, both due to the risk that the tubing would sorb contaminants and the propensity of this tubing to contribute organic compounds to the sample.

   Samples shall be collected without contact with the pump-head tubing using vacuum transfer caps for analyses requiring 1-liter glass containers and the use of the 'soda-straw' method (in accordance with Section 3.7.1 of *Groundwater Sampling*, SESDPROC-301-R4, as described in the next section) for the filling of VOC vials.

   VOC analyses requiring sampled collected in a 40 mL glass vial with Teflon® septa should be collected with as little agitation or disturbance as possible. The vial should be filled so that there is a meniscus at the top of the vial and no bubbles or headspace should be present in the vial after it is capped. After the cap is securely tightened, the vial should be inverted and tapped on the palm to check if any undetected bubbles are dislodged. If a bubble or bubbles are present, the vial should be topped off using a minimal amount of sample to re-establish the meniscus. Care should be taken not to flush any preservative out of the vial during topping off. If, after topping off and capping the vial, bubbles are still present, a new vial should be obtained, and the sample re-collected.
6. Place the sample bottles into a cooler with ice upon sample collection.

When utilizing a peristaltic pump to collect samples for VOC analysis, the "soda straw" method as described below shall be utilized in accordance to Section 3.7.1 of the EPA Region 4 Groundwater Sampling guidance and summarized below:

1. When an adequate purge has been achieved, make a kink or otherwise mark the tubing at the top of the casing in case the tubing needs to be reinserted for additional sample volume. Slowly remove the tubing from the well and coil it in one hand in loose coils.
2. Remove the top from a 40 mL VOC vial and position the end of the sample tubing near the top of the vial. Reverse the pump direction and turn the speed knob to its slowest position. Turn on the pump and slowly increase speed until water slowly fills the vial. Fill the vial with a slow laminar flow that does not agitate the water in the vial or entrain bubbles. Continue to fill the vial until a convex meniscus forms on the top of the vial and turn off the pump.

Other general procedures that are followed during sampling include:

- Avoid rinsing the sample bottles before filling.
- Collect water sample from the pump's discharge line directly into laboratory-supplied containers appropriate for the specific analysis being conducted.
- Open only one sample container at a time. Immediately replace the container's cap and make sure the label is completed before starting to fill the next bottle.

- Minimize the potential for contamination to sample containers and equipment by sampling up wind and/or removing contaminants before opening containers.
- Common contaminants may include dust or other particulate matter.
- Immediately put the cap on each bottle after filling it.
- Place filled sample bottle into an iced cooler and enter sample information onto the appropriate chain of custody forms.

If bladder pumps are used for groundwater sampling, the sample procedures to use with the bladder pumps will be in accordance with *Groundwater Sampling*, SESDPROC-301-R4.

10.3 Documentation of Field Sampling Activities

Field sampling activities shall be recorded on field forms by personnel conducting the field sampling procedures. Pertinent data will vary based on site conditions; however, date, job number, project name, sampling location, sample depth, sample identification, and sample description, along with any screening results and general observations, updates to well signage or access, and pump conditions should be clearly noted for each monitoring well in the field sheet forms or in a dedicated field logbook.

11.0 SAMPLE HANDLING AND PRESERVATION

Other general procedures that are followed following sampling include:

1. All sample containers shall be filled to the top as to form a meniscus at the top of the vials, capped with a Teflon seal, and placed on ice immediately after sampling. On arrival at the laboratory they will be transferred to a refrigerator.
2. Temperature, specific conductance, pH, turbidity, and dissolved oxygen shall be recorded as ground water is being purged from the well in accordance with the following EPA Region 4 SESD Operating Procedures: *Field pH Measurement*, LSASDPROC-100-R5, effective date July 23, 2020; *Field Specific Conductance Measurement*, LSASDPROC-101-R7, effective date May 5, 2020; *Field Temperature Measurement*, SESDPROC-102-R5, effective date March 14, 2018; *Field Turbidity Measurement*, SESDPROC-103-R4, effective date July 27, 2017; and *Field Measurement of Dissolved Oxygen*, SESDPROC-106-R4, effective date April 12, 2017;

   Stabilization of these parameters is used to indicate groundwater quality not impacted by well casing material and when sampling may occur in accordance with EPA Region 4 SESD Operating Procedure *Groundwater Sampling*, SESDPROC-301-R4, effective date April 26, 2017.

3. Sample delivery to the laboratory shall be in the shortest possible time after collection. If delay is incurred this shall be entered in the field logbook along with the time increment.
4. A distilled water blank, or field blank, shall be carried to the field and put through the entire sampling procedure. This process shall be completed a minimum of one (1) per day of sampling activity. If positives are found, this will alert the collector to field sampling error and potential laboratory reporting biases.

11.1 Chain-of-Custody

Custody and protection of samples is an important legal consideration. As few people as possible should handle the samples. The sampler is personally responsible for collected samples, and shall be able to attest to the integrity of samples until transfer. If the samples are placed in a vehicle, it shall be kept locked. Any ice chest shall be locked, or located in a place that is locked with access only by responsible officials.

A Chain-of-Custody form shall be used to document the handling of samples from the moment of collection until testing. The ID number of each sampling point shall be entered in a sampling logbook along with a word description of the sample. Note that several bottles collected for different parameters will have the same ID number if they come from one (1) sampling point.

The Chain-of-Custody form shall contain the Site name, date of sampling and name of the collector. Each transfer of custody is recorded with an appropriate signature, date, and time. If the samples are to be shipped, they must be sealed. The driver for the delivery service must sign the custody form and a bill of lading must be secured.

12.0 LABORATORY PROCEDURES

The laboratory performing the analyses shall specify a method in EPA Manual SW-846, EPA 600/4-79020, or other EPA approved method. Records of groundwater analyses shall include the methods used (by number), the extraction date, and date of actual analysis. Data from samples that are not analyzed within recommended holding times shall be considered suspect. Any deviation from an EPA approved method shall be adequately tested to ensure that the quality of the results meets the performance specifications (e.g., detection limit, sensitivity, precision, accuracy) of the reference method. A planned deviation shall be justified and submitted for approval by EPD prior to use.

13.0 FIELD AND LABORATORY QUALITY ASSURANCE

The Site owner or their delegated consultants shall ensure the reliability of the analytical data being gathered during the monitoring program and verify that quality assurance/quality control (QA/QC) procedures are maintained. A field blank shall be taken at least once for every ten (10) samples. Distilled or deionized water is taken to the Site and handled like a sample. It is poured into a bailer, or extracted using the same pumping equipment, and sample bottles are filled using an identical technique. Analyses of the blank alerts the sampler to technical error. The blank test results are not used to correct the sample results but are reported as-is. If the contaminant levels in the blank are within an order of magnitude of the ground water sample results, the wells shall be resampled. Additionally, a trip blank provided by the laboratory for each sampling blank shall be carried to and from the field and maintained with the samples collected during the event. The trip blank shall be analyzed for VOCs by EPA Method 8260B.

In selecting a laboratory to conduct analyses of groundwater samples, it shall be the Site owner or their delegated consultant’s responsibility to ensure that the laboratory of choice is National Environmental Laboratory Accreditation Program (NELAP) certified for the appropriate analytical methods being performed and exercising a proper QA/QC program as described in the sampling plan. The approved EPA test methods contain within them the requirement to run a spiked sample to determine percent recovery. This shall be a part of the lab report. Additional quality control such as field blanks (minimum of 1 per day of sampling), a Trip Blank (VOCs only), method blanks, matrix spike/matrix spike duplicate (MS/MSD) (5% of samples collected), and duplicates (5 to 10% of samples collected) are also described in the test method and shall be included in the laboratory work agreement. In accordance with *Field Sampling Quality Control,* SESDPROC-011-R5, effective date April 26, 2017, a minimum of 5%, but no more than 10% of all samples will be collected as duplicates. The laboratory QA program shall be a part of this plan. Quality assurance procedures are time consuming and increase the cost of testing. However, the Site shall be regulated based on the results. It is to the Site owner or their delegated consultant’s advantage to employ a qualified laboratory. Field instruments shall be calibrated prior to field use and recalibrated in the field before measuring each sample.

14.0 DATA EVALUATION AND REPORTING

Groundwater monitoring data will be evaluated to assess the effectiveness of various remedial actions completed at the site (i.e., soil removal, capping, and/or engineering/institutional controls associated with the various LUCs), monitor groundwater quality at the property boundary to protect potential offsite receptors not covered under the site LUCs, and implement post-closure care for three solid waste areas (i.e., pond area, dredge spoil area, and gypsum piles) which were closed in general accordance with the Georgia Solid Waste Management Rules.

Groundwater COCs and monitoring analytes were selected based on results of the human health risk assessment in the RFI and comparisons of maximum detected concentrations to HSRA and RCRA. Residential and non-residential goals were developed for the site under several different exposure scenarios and LUC applications. For decision making purposes, analytical results from each semi-annual event will be compared to residential and non-residential cleanup goals summarized and described below.

The groundwater unrestricted use remediation goal assumes future residential use of groundwater for domestic purposes (direct contact exposure pathways) and inhalation exposure from the vapor intrusion pathway. Groundwater remedial goals for unrestricted use were calculated with a target cancer risk of 1 in 1,000,000 (1 x 10^{-6}) or a noncancer hazard quotient (HQ) equal to 1.

The non-residential action level assumes residential domestic use of groundwater is prohibited through the application of LUCs. Three different types of non-residential groundwater action levels were calculated, as listed below:

- Non-residential groundwater action level;
- RCRA Risk-Based Non-Residential Vapor Intrusion Action Level; and
- RCRA Risk-Based Construction Worker Action Level.

All non-residential RCRA goals were calculated with a target cancer risk of 1 in 100,000 (1 x 10^{-5}) or a noncancer HQ equal to 1. Because the target cancer risk is higher for the non-residential scenario and the assumed exposure is reduced for non-residential receptors, the list of non-residential COCs does not include several of the residential COCs. These COCs are: 1,1-biphenyl, beryllium, cadmium, cobalt, dibenzofuran, nickel, selenium, thallium, and vanadium.

Semi-annual groundwater monitoring reports will be prepared and submitted to GA EPD as required by the PPCAP following validation of the laboratory analytical results. Groundwater analytical data will be evaluated to determine whether or not the remedy construction is effective in achieving groundwater RAOs. The monitoring results will be statistically evaluated to determine COC concentration trends and compared to the cleanup goals on a point-by-point basis. Following the interpretation of the results recommendations regarding continued monitoring will be made in the semi-annual monitoring reports.

The semi-annual groundwater monitoring reports shall be submitted to the EPD within 90 days after each sampling event. The groundwater monitoring reports shall include the following:

- A certification statement signed by a qualified groundwater scientist certifying compliance or non-compliance with established standards;
- Certification by a licensed Professional Geologist or Engineer;

- A brief discussion of the Site geology/hydrogeology
- A discussion of the Site's history and groundwater compliance status and monitoring system current status, including all approved sampling locations;
- Documentation of the integrity of damaged wells;
- A brief overview of purging/sampling methodologies;
- Discussion of results;
- Comparisons to established standards;
- Recommendations for future monitoring consistent with the Rules;
- Potentiometric surface map(s);
- Isoconcentration map(s);
- Cross section(s) depicting the horizontal and vertical extent of groundwater plumes in the UWBZ and LWBZ;
- Calculations of flow rate;
- Tabulated water level measurements collected within 24 hours (Tidally-influenced LWBZ monitoring wells shall be taken within a short timeframe (<2 hours) bracketing high or low tides);
- Field sampling logs for each monitoring location that include monitoring point conditions;
- NELAP Certification;
- Tabulated field parameters;
- Laboratory Chain-of-Custodies;
- Laboratory Analytical Data, and
- Statistical analysis of the groundwater laboratory analytical results and groundwater COC concentration trends.

The report will always include a completed copy of standard EPD Form SWM-23 and in accordance with the reporting requirements outlined in *Section 391-3-4-.17(6) of the Rules for Solid Waste Management*. Reports will be forwarded to:

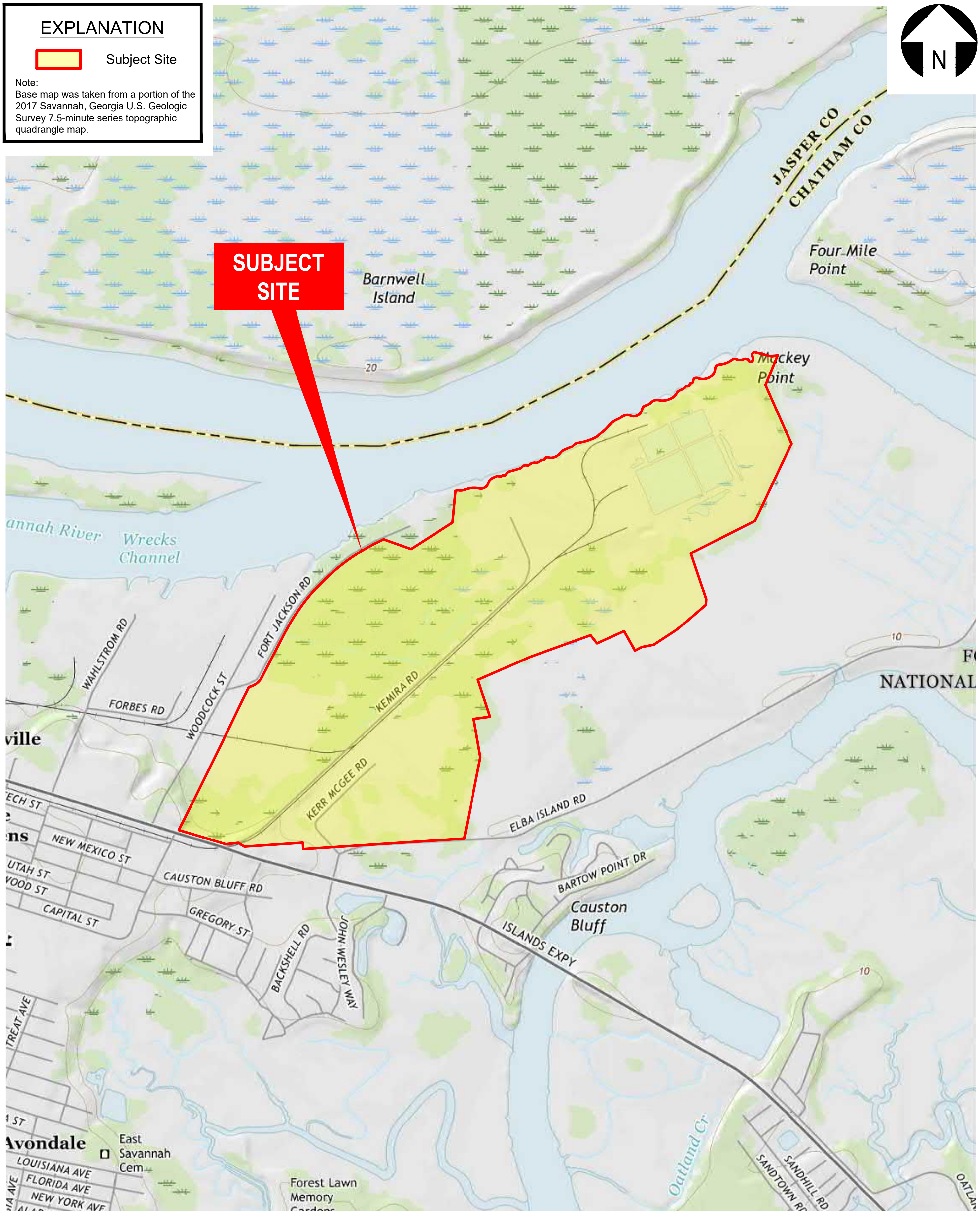
Department of Natural Resources
Georgia Environmental Protection Division
Hazardous Waste Corrective Action Program
2 Martin Luther King Jr. Drive, Suite 1054
Atlanta, Georgia 30334-9000

A copy of each report will also be kept at the Site in the operating record.

In accordance with the Water Well Standards Act, every five (5) years, a professional geologist or engineer registered in the State of Georgia will inspect the wells, certify the integrity of each well, supervise appropriate remedial measures, and submit the appropriate documentation to EPD.

APPENDIX A

FIGURES



EXPLANATION

🟨 Subject Site

Note:
Base map was taken from a portion of the 2017 Savannah, Georgia U.S. Geologic Survey 7.5-minute series topographic quadrangle map.

0 1,000' 2,000'
1" = 2,000'
SCALE IN FEET

Project Mngr: WSA
Drawn By: JDG
Checked By: WAE
Approved By: WSA

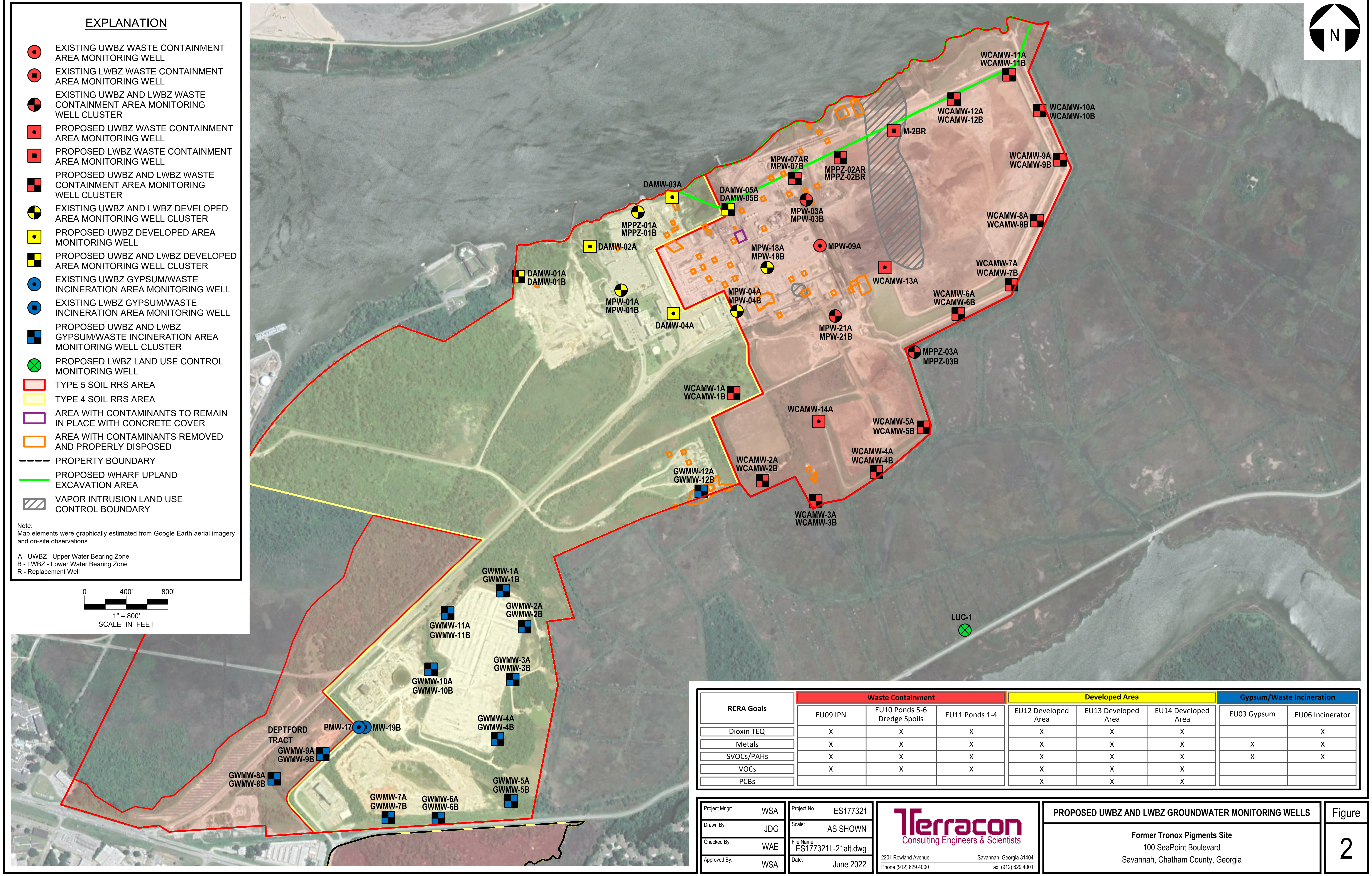
Project No. ES177321
Scale: AS SHOWN
File Name: ES177321L-21alt.dwg
Date: March 2021

Terracon
Consulting Engineers & Scientists
2201 Rowland Avenue Savannah, Georgia 31404
Phone (912) 629 4000 Fax. (912) 629 4001

GENERAL VICINITY MAP

Former Tronox Pigments Site
100 SeaPoint Boulevard
Savannah, Chatham County, Georgia

Figure
1



EXPLANATION

- EXISTING UWBZ WASTE CONTAINMENT AREA MONITORING WELL
- EXISTING LWBZ WASTE CONTAINMENT AREA MONITORING WELL
- EXISTING UWBZ AND LWBZ WASTE CONTAINMENT AREA MONITORING WELL CLUSTER
- PROPOSED UWBZ WASTE CONTAINMENT AREA MONITORING WELL
- PROPOSED LWBZ WASTE CONTAINMENT AREA MONITORING WELL
- PROPOSED UWBZ AND LWBZ WASTE CONTAINMENT AREA MONITORING WELL CLUSTER
- EXISTING UWBZ AND LWBZ DEVELOPED AREA MONITORING WELL CLUSTER
- PROPOSED UWBZ DEVELOPED AREA MONITORING WELL
- PROPOSED UWBZ AND LWBZ DEVELOPED AREA MONITORING WELL CLUSTER
- EXISTING UWBZ GYPSUM/WASTE INCINERATION AREA MONITORING WELL
- EXISTING LWBZ GYPSUM/WASTE INCINERATION AREA MONITORING WELL
- PROPOSED UWBZ AND LWBZ GYPSUM/WASTE INCINERATION AREA MONITORING WELL CLUSTER
- PROPOSED LWBZ LAND USE CONTROL MONITORING WELL
- TYPE 5 SOIL RRS AREA
- TYPE 4 SOIL RRS AREA
- AREA WITH CONTAMINANTS TO REMAIN IN PLACE WITH CONCRETE COVER
- AREA WITH CONTAMINANTS REMOVED AND PROPERLY DISPOSED
- PROPERTY BOUNDARY
- PROPOSED WHARF UPLAND EXCAVATION AREA
- VAPOR INTRUSION LAND USE CONTROL BOUNDARY

Note:
Map elements were graphically estimated from Google Earth aerial imagery and on-site observations.

A - UWBZ - Upper Water Bearing Zone
B - LWBZ - Lower Water Bearing Zone
R - Replacement Well

RCRA Goals	Waste Containment			Developed Area			Gypsum/Waste Incineration	
	EU09 IPN	EU10 Ponds 5-6 Dredge Spoils	EU11 Ponds 1-4	EU12 Developed Area	EU13 Developed Area	EU14 Developed Area	EU03 Gypsum	EU06 Incinerator
Dioxin TEQ	X	X	X	X	X	X		X
Metals	X	X	X	X	X	X	X	X
SVOCs/PAHs	X	X	X	X	X	X	X	X
VOCs	X	X	X	X	X	X		
PCBs				X	X	X		

Project Mngr:	WSA
Drawn By:	JDG
Checked By:	WAE
Approved By:	WSA
Project No.	ES177321
Scale:	AS SHOWN
File Name:	ES177321L-21alt.dwg
Date:	June 2022

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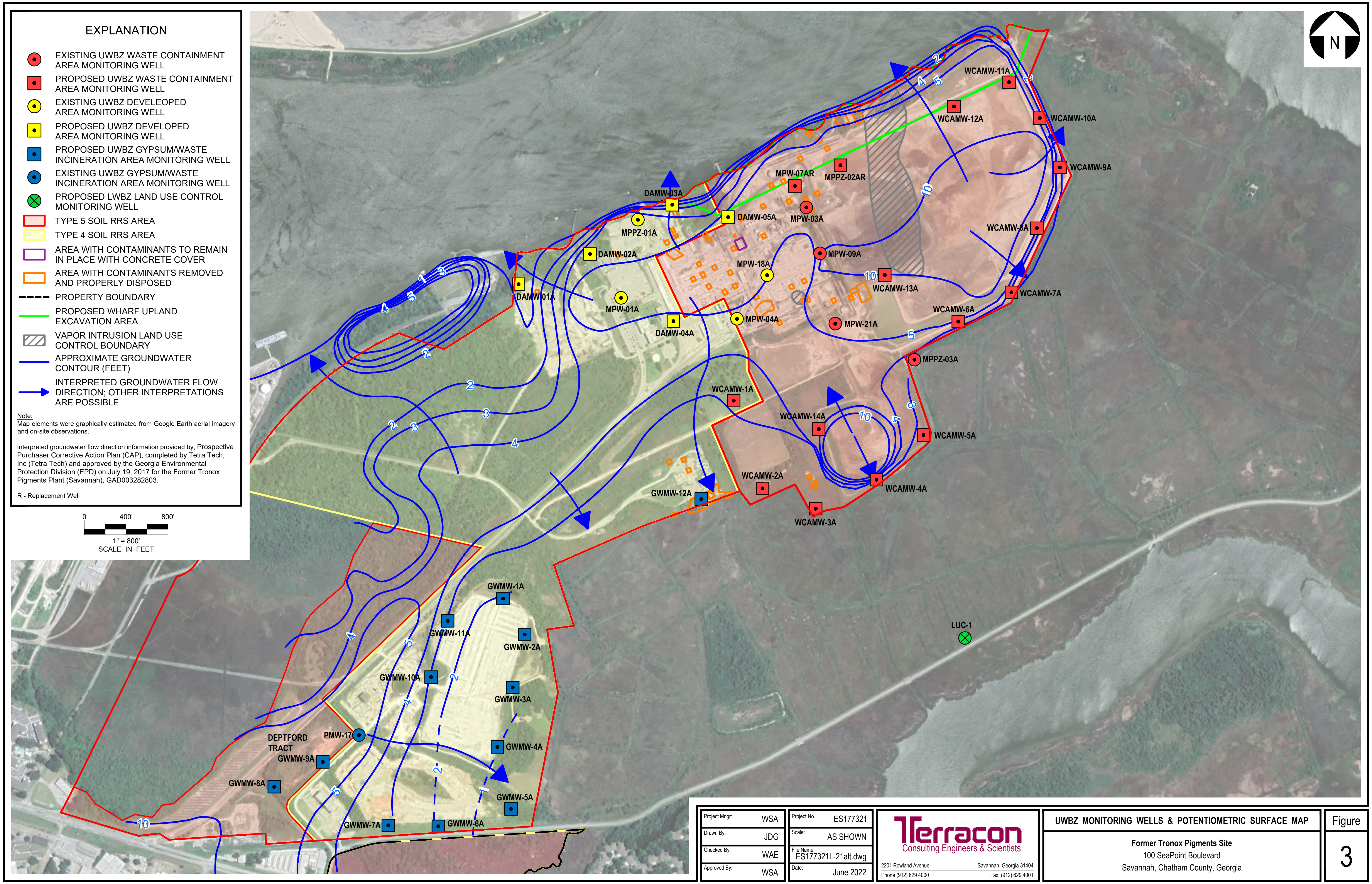
PROPOSED UWBZ AND LWBZ GROUNDWATER MONITORING WELLS

Former Tronox Pigments Site
100 SeaPoint Boulevard
Savannah, Chatham County, Georgia

Figure
2



EXPLANATION

●	EXISTING UWBZ WASTE CONTAINMENT AREA MONITORING WELL
■	PROPOSED UWBZ WASTE CONTAINMENT AREA MONITORING WELL
●	EXISTING UWBZ DEVELEOPED AREA MONITORING WELL
■	PROPOSED UWBZ DEVELOPED AREA MONITORING WELL
■	PROPOSED UWBZ GYPSUM/WASTE INCINERATION AREA MONITORING WELL
●	EXISTING UWBZ GYPSUM/WASTE INCINERATION AREA MONITORING WELL
⊗	PROPOSED LWBZ LAND USE CONTROL MONITORING WELL
🟥	TYPE 5 SOIL RRS AREA
🟨	TYPE 4 SOIL RRS AREA
☐	AREA WITH CONTAMINANTS TO REMAIN IN PLACE WITH CONCRETE COVER
☐	AREA WITH CONTAMINANTS REMOVED AND PROPERLY DISPOSED
- - -	PROPERTY BOUNDARY
—	PROPOSED WHARF UPLAND EXCAVATION AREA
▨	VAPOR INTRUSION LAND USE CONTROL BOUNDARY
—	APPROXIMATE GROUNDWATER CONTOUR (FEET)
→	INTERPRETED GROUNDWATER FLOW DIRECTION; OTHER INTERPRETATIONS ARE POSSIBLE

Note:
Map elements were graphically estimated from Google Earth aerial imagery and on-site observations.

Interpreted groundwater flow direction information provided by, Prospective Purchaser Corrective Action Plan (CAP), completed by Tetra Tech, Inc (Tetra Tech) and approved by the Georgia Environmental Protection Division (EPD) on July 19, 2017 for the Former Tronox Pigments Plant (Savannah), GAD003282803.

R - Replacement Well

0 400' 800'
1" = 800'
SCALE IN FEET

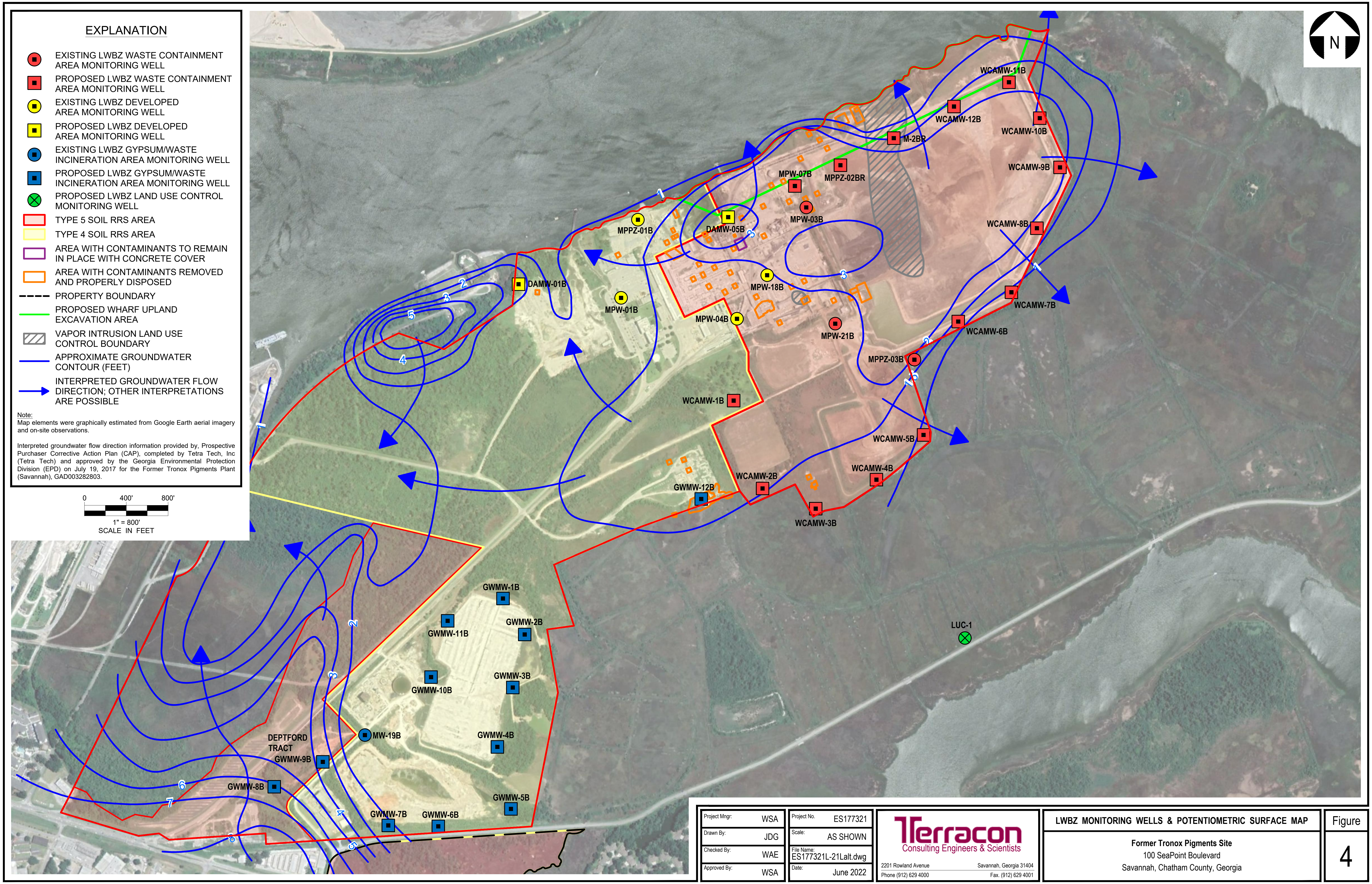
Project Mngr:	WSA	Project No.	ES177321
Drawn By:	JDG	Scale:	AS SHOWN
Checked By:	WAE	File Name:	ES177321L-21alt.dwg
Approved By:	WSA	Date:	June 2022

Terracon
Consulting Engineers & Scientists
2201 Rowland Avenue Savannah, Georgia 31404
Phone (912) 629 4000 Fax. (912) 629 4001

UWBZ MONITORING WELLS & POTENTIOMETRIC SURFACE MAP

Former Tronox Pigments Site
100 SeaPoint Boulevard
Savannah, Chatham County, Georgia

Figure
3



EXPLANATION

●	EXISTING LWBZ WASTE CONTAINMENT AREA MONITORING WELL
■	PROPOSED LWBZ WASTE CONTAINMENT AREA MONITORING WELL
●	EXISTING LWBZ DEVELOPED AREA MONITORING WELL
■	PROPOSED LWBZ DEVELOPED AREA MONITORING WELL
●	EXISTING LWBZ GYPSUM/WASTE INCINERATION AREA MONITORING WELL
■	PROPOSED LWBZ GYPSUM/WASTE INCINERATION AREA MONITORING WELL
⊗	PROPOSED LWBZ LAND USE CONTROL MONITORING WELL
🟥	TYPE 5 SOIL RRS AREA
🟨	TYPE 4 SOIL RRS AREA
☐	AREA WITH CONTAMINANTS TO REMAIN IN PLACE WITH CONCRETE COVER
☐	AREA WITH CONTAMINANTS REMOVED AND PROPERLY DISPOSED
- - -	PROPERTY BOUNDARY
—	PROPOSED WHARF UPLAND EXCAVATION AREA
▨	VAPOR INTRUSION LAND USE CONTROL BOUNDARY
—	APPROXIMATE GROUNDWATER CONTOUR (FEET)
→	INTERPRETED GROUNDWATER FLOW DIRECTION; OTHER INTERPRETATIONS ARE POSSIBLE

Note:
Map elements were graphically estimated from Google Earth aerial imagery and on-site observations.

Interpreted groundwater flow direction information provided by, Prospective Purchaser Corrective Action Plan (CAP), completed by Tetra Tech, Inc (Tetra Tech) and approved by the Georgia Environmental Protection Division (EPD) on July 19, 2017 for the Former Tronox Pigments Plant (Savannah), GAD003282803.

0 400' 800'
1" = 800'
SCALE IN FEET

Project Mngr:	WSA	Project No.	ES177321
Drawn By:	JDG	Scale:	AS SHOWN
Checked By:	WAE	File Name:	ES177321L-21Lalt.dwg
Approved By:	WSA	Date:	June 2022

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LWBZ MONITORING WELLS & POTENTIOMETRIC SURFACE MAP

Former Tronox Pigments Site
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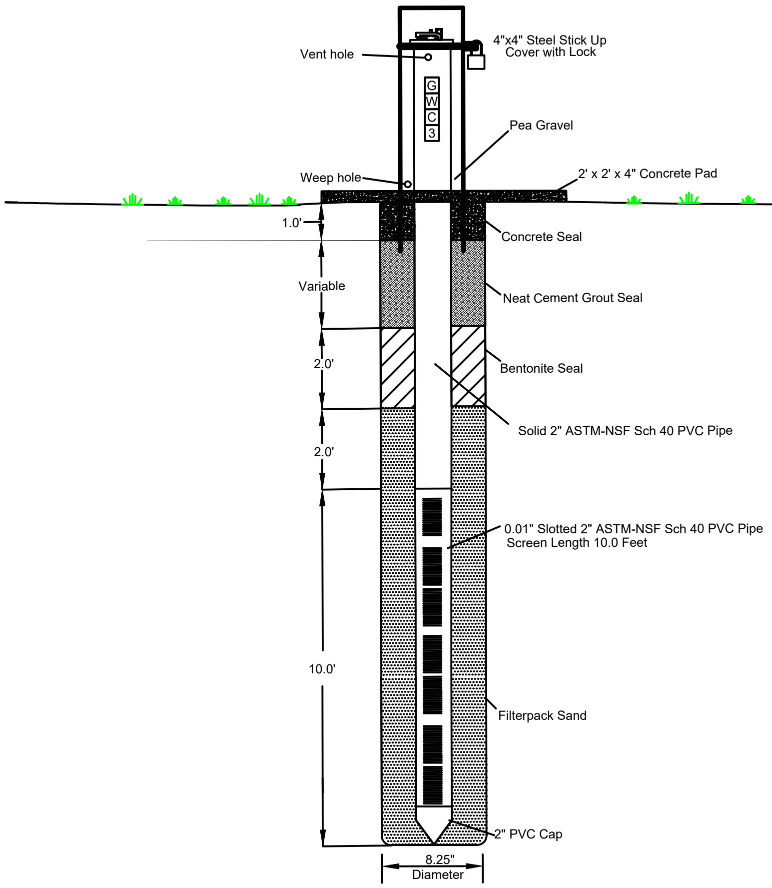
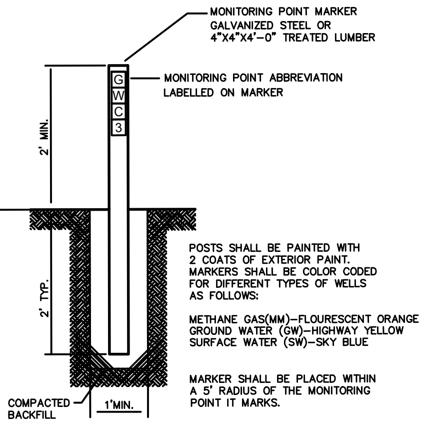
Savannah, Chatham County, Georgia

Figure
4



Typical Groundwater Monitoring Well



POSTS SHALL BE PAINTED WITH 2 COATS OF EXTERIOR PAINT. MARKERS SHALL BE COLOR CODED FOR DIFFERENT TYPES OF WELLS AS FOLLOWS:

METHANE GAS(MM)–FLOURESCENT ORANGE
GROUND WATER (GW)–HIGHWAY YELLOW
SURFACE WATER (SW)–SKY BLUE

MARKER SHALL BE PLACED WITHIN A 5' RADIUS OF THE MONITORING POINT IT MARKS.

PERMANENT MONITORING POINT MARKER DETAIL
N.T.S.

Project Mngr:	WSA	Project No.	ES177321
Drawn By:	JDG	Scale:	As Shown
Checked By:	WAE	File Name:	ES177321L-21alt.dwg
Approved By:	WSA	Date:	March 2021

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TYPICAL MONITORING WELL DETAIL

Former Tronox Pigments Site
100 SeaPoint Boulevard
Savannah, Chatham County, Georgia

Figure
5

APPENDIX B

TABLES

Former Tronox Pigments Site

100 SeaPoint Boulevard
Savannah, Chatham County, Georgia
HSI No. 10179
Terracon Project No. ES177321L

TABLE 1: GROUNDWATER MONITORING PROGRAM SUMMARY

Analyte	Groundwater Unrestricted Use Remedial Goal (µg/L)		Non-Residential Groundwater Action Level (µg/L)		RCRA Risk-Based Non-Residential Vapor Intrusion Action Level (µg/L)		RCRA Risk-Based Construction Worker Action Level (µg/L)		Laboratory Detection Limit (µg/L)	Waste Containment Area			Developed Area			Gypsum/Waste Incinerator Area	
										EU-09	**EU-10**	**EU-11**	**EU-12**	**EU-13**	**EU-14**	**EU-02, EU-03**	**EU-06**
										IPN	Dredge Spoils; Ponds 5-6	Ponds 1-4	DA	DA	DA	Gypsum	Incinerator
										UWBZ			**UWBZ**			**UWBZ**	**UWBZ**
										MPPZ-02AR, MPPZ-03A, MPW-03A, MPW-07AR, MPW-09A, MPW-21A, WCAMW-1A, WCAMW-2A, WCAMW-3A, WCAMW-4A, WCAMW-5A, WCAMW-6A, WCAMW-7A, WCAMW-8A, WCAMW-9A, WCAMW-10A, WCAMW-11A, WCAMW-12A, WCAMW-13A, WCAMW-14A			MPPZ-01A, MPW-01A, MPW-04A, MPW-18A, DAMW-01A, DAMW-02A, DAMW-03A, DAMW-04A, DAMW-05A			PMW-17, GWMW-1A, GWMW-2A, GWMW-3A, GWMW-4A, GWMW-5A, GWMW-6A, GWMW-7A, GWMW-8A, GWMW-9A, GWMW-10A, GWMW-11A	GWMW-12A
										LWBZ			**LWBZ**			**LWBZ**	**LWBZ**
										MPW-21B, M-2BR, MPPZ-02BR, MPPZ-03B, MPW-03B, MPW-07B, WCAMW-1B, WCAMW-2B, WCAMW-3B, WCAMW-4B, WCAMW-5B, WCAMW-6B, WCAMW-7B, WCAMW-8B, WCAMW-9B, WCAMW-10B, WCAMW-11B, WCAMW-12B			MPPZ-01B, MPW-01B, MPW-04B, MPW-18B, DAMW-01B, DAMW-05B			MW-19B, GWMW-1B, GWMW-2B, GWMW-3B, GWMW-4B, GWMW-5B, GWMW-6B, GWMW-7B, GWMW-8B, GWMW-9B, GWMW-10B, GWMW-11B	GWMW-12B
Dioxins/Furans Constituents by EPA Methods 613, 8280, and 8290										X	X	X	X	X	X		X
Dioxin TEQ	3.00E-05	MCL	3.00E-05	MCL	1.58E-03	RCRA-VI	3.00E-05	MCL	3.06E-06	X	X	X	X	X	X	NR	X
Inorganic Constituents by EPA Methods 6010, 7040, 7041 and 7196A										X	X	X	X	X	X	X	X
Aluminum	4.00E+03	RCRA	3.11E+04	NC IW DC	--	--	2.50E+06	NC CW	100	X	X	X	X	X	X	X	X
Antimony	3.90E+00	RCRA	--	--	--	--	--	--	2.53	X	X	X	X	X	X	X	X
Arsenic	1.00E+01	MCL	1.00E+01	MCL	--	--	5.63E+02	NC CW	4.65	X	X	X	X	X	X	X	X
Barium	--	--	--	--	--	--	--	--	1	M	M	M	M	M	M	M	M
Beryllium	4.00E+00	MCL	--	--	--	--	--	--	1.02	X	X	X	X	X	X	X	X
Cadmium	5.00E+00	MCL	--	--	--	--	--	--	0.5	X	X	X	X	X	X	X	X
Chromium	1.00E+02	MCL	1.40E+05	NC IW DC	--	--	1.93E+07	NC CW	1.55	X	X	X	X	X	X	X	X
Cobalt	8.00E-01	BTV	--	--	--	--	--	--	1.19	X	X	X	X	X	X	X	X
Copper	1.30E+03	MCL	1.87E+03	NC IW DC	--	--	1.50E+05	NC CW	2.64	X	X	X	X	X	X	X	X
Iron	3.00E+04	BTV	3.27E+04	NC IW DC	--	--	2.63E+06	NC CW	25	X	X	X	X	X	X	X	X
Lead	1.50E+01	MCL	1.50E+01	MCL	--	--	1.50E+01	MCL	2.66	X	X	X	X	X	X	X	X
Manganese	5.10E+03	BTV	5.10E+03	BTV	--	--	--	--	2.97	X	X	X	X	X	X	X	X
Nickel	4.33E+01	RCRA	--	--	--	--	--	--	3.02	X	X	X	X	X	X	X	X
Selenium	5.00E+01	MCL	--	--	--	--	--	--	4.75	X	X	X	X	X	X	X	X
Silver	--	--	--	--	--	--	--	--	1	M	M	M	M	M	M	M	M
Thallium	2.00E+00	MCL	--	--	--	--	--	--	2.00	X	X	X	X	X	X	X	X
Vanadium	6.62E+00	RCRA	--	--	--	--	--	--	1.3	X	X	X	X	X	X	X	X
Zinc	--	--	--	--	--	--	--	--	8	M	M	M	M	M	M	M	M
Hexavalent Chromium	1.00E+02	MCL	1.40E+05	NC IW DC	--	--	1.93E+07	NC CW	1.55	NR	NR	NR	X	X	X	X	NR
Semi-Volatile Organic Constituents by EPA Method 8270										X	X	X	X	X	X	X	X
1,1-Biphenyl	6.38E-02	RCRA	--	--	--	--	--	--	1.64	X	X	X	X	X	X	X	X
1,3-Dichlorobenzene	--	--	--	--	--	--	--	--	1.77	M	M	M	M	M	M	M	M
2,4-Dichlorophenol	--	--	--	--	--	--	--	--	1.41	M	M	M	M	M	M	M	M
2,4-Dimethylphenol	--	--	--	--	--	--	--	--	1.26	M	M	M	M	M	M	M	M
1,2,4,5-Tetrachlorobenzene	--	--	--	--	--	--	--	--	2.47	M	M	M	M	M	M	M	M
2,6-Dinitrotoluene	--	--	--	--	--	--	--	--	1.46	M	M	M	M	M	M	M	M
Acetophenone	--	--	--	--	--	--	--	--	1.75	M	M	M	M	M	M	M	M

Former Tronox Pigments Site

100 SeaPoint Boulevard
Savannah, Chatham County, Georgia
HSI No. 10179
Terracon Project No. ES177321L

TABLE 1: GROUNDWATER MONITORING PROGRAM SUMMARY

Analyte	**Groundwater Unrestricted Use Remedial Goal** (µg/L)		**Non-Residential Groundwater Action Level** (µg/L)		**RCRA Risk-Based Non-Residential Vapor Intrusion Action Level** (µg/L)		**RCRA Risk-Based Construction Worker Action Level** (µg/L)		**Laboratory Detection Limit** (µg/L)	**Waste Containment Area**			**Developed Area**			**Gypsum/Waste Incinerator Area**	
										EU-09	**EU-10**	**EU-11**	**EU-12**	**EU-13**	**EU-14**	**EU-02, EU-03**	**EU-06**
										IPN	Dredge Spoils; Ponds 5-6	Ponds 1-4	DA	DA	DA	Gypsum	Incinerator
										UWBZ			**UWBZ**			**UWBZ**	**UWBZ**
										MPPZ-02AR, MPPZ-03A, MPW-03A, MPW-07AR, MPW-09A, MPW-21A, WCAMW-1A, WCAMW-2A, WCAMW-3A, WCAMW-4A, WCAMW-5A, WCAMW-6A, WCAMW-7A, WCAMW-8A, WCAMW-9A, WCAMW-10A, WCAMW-11A, WCAMW-12A, WCAMW-13A, WCAMW-14A			MPPZ-01A, MPW-01A, MPW-04A, MPW-18A, DAMW-01A, DAMW-02A, DAMW-03A, DAMW-04A, DAMW-05A			PMW-17, GWMW-1A, GWMW-2A, GWMW-3A, GWMW-4A, GWMW-5A, GWMW-6A, GWMW-7A, GWMW-8A, GWMW-9A, GWMW-10A, GWMW-11A	GWMW-12A
										LWBZ			**LWBZ**			**LWBZ**	**LWBZ**
										MPW-21B, M-2BR, MPPZ-02BR, MPPZ-03B, MPW-03B, MPW-07B, WCAMW-1B, WCAMW-2B, WCAMW-3B, WCAMW-4B, WCAMW-5B, WCAMW-6B, WCAMW-7B, WCAMW-8B, WCAMW-9B, WCAMW-10B, WCAMW-11B, WCAMW-12B			MPPZ-01B, MPW-01B, MPW-04B, MPW-18B, DAMW-01B, DAMW-05B			MW-19B, GWMW-1B, GWMW-2B, GWMW-3B, GWMW-4B, GWMW-5B, GWMW-6B, GWMW-7B, GWMW-8B, GWMW-9B, GWMW-10B, GWMW-11B	GWMW-12B
Benzaldehyde	--	--	--	--	--	--	--	--	2.67	M	M	M	M	M	M	M	M
Benzyl Alcohol	--	--	--	--	--	--	--	--	1.12	M	M	M	M	M	M	M	M
Bis(2-Chloroethyl)Ether	1.40E-02	RCRA	5.63E-01	C IW DC	8.27E+02	RCRA-VI	1.56E+01	C CW	1.51	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
bis(2-ethylhexyl)phthalate	--	--	--	--	--	--	--	--	1.85	M	M	M	M	M	M	M	M
Butyl Benzul Phthalate	--	--	--	--	--	--	--	--	2.04	M	M	M	M	M	M	M	M
Caprolactam	--	--	--	--	--	--	--	--	3.06	M	M	M	M	M	M	M	M
Carbazole	--	--	--	--	--	--	--	--	0.97	M	M	M	M	M	M	M	M
Dibenzofuran	6.08E-01	RCRA	--	--	--	--	--	--	1.47	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Di-n-octyl phthalate	--	--	--	--	--	--	--	--	1.60	M	M	M	M	M	M	M	M
Hexachlorobenzene	--	--	--	--	--	--	--	--	1.96	M	M	M	M	M	M	M	M
Pentachlorobenzene	--	--	--	--	--	--	--	--	0.7	M	M	M	M	M	M	M	M
Pentachlorophenol	1.00E+00	MCL	4.95E+00	HSRA	--	--	3.89E+01	NC CW	1	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Phenanthrene	2.00E-01	HSRA	--	--	--	--	2.01E+02	NC CW	0.11	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Volatile Organic Constituents by EPA Method 8260										X	X	X	X	X	X		
1,1-Dichloroethane	2.80E+00	RCRA	1.14E+02	C IW DC	4.23E+02	RCRA-VI	6.45E+02	C CW	0.622	**X**	**X**	**X**	**X**	**X**	**X**	NR	NR
1,1-Dichloroethene	7.00E+00	MCL	1.34E+00	NC CW	1.28E+02	RCRA-VI	1.34E+00	NC CW	0.17	**X**	**X**	**X**	**X**	**X**	**X**	NR	NR
1,2,4-Trimethylbenzene	--	--	--	--	--	--	--	--	0.422	M	M	M	M	M	M	NR	NR
1,2-Dibromo-3-Chloropropane	3.30E-04	RCRA	4.01E-02	C IW DC	5.06E+00	RCRA-VI	7.56E-02	NC CW	1	**X**	**X**	**X**	**X**	**X**	**X**	NR	NR
1,2-Dichloroethane	1.70E-01	RCRA	1.34E+00	NC CW	1.28E+02	RCRA-VI	1.34E+00	NC CW	0.17	**X**	**X**	**X**	**X**	**X**	**X**	NR	NR
1,3,5-Trimethylbenzene	--	--	--	--	--	--	--	--	0.433	M	M	M	M	M	M	NR	NR
1,4-Dioxane	4.60E-01	RCRA	1.70E+01	C IW DC	1.72E+05	RCRA-VI	6.88E+01	NC CW	0.5	**X**	**X**	**X**	**X**	**X**	**X**	NR	NR
2-Butanone	--	--	--	--	--	--	--	--	5.00	M	M	M	M	M	M	NR	NR
4-Isopropyltoluene	--	--	--	--	--	--	--	--	0.333	M	M	M	M	M	M	NR	NR
4-Methyl-2-Pentanone	--	--	--	--	--	--	--	--	10.0	M	M	M	M	M	M	NR	NR
Acetone	--	--	--	--	--	--	--	--	10.0	M	M	M	M	M	M	NR	NR
Benzene	5.00E+00	MCL	8.72E+00	HSRA	8.98E+01	RCRA-VI	1.95E+01	NC CW	0.657	**X**	**X**	**X**	**X**	**X**	**X**	NR	NR
Carbon Disulfide	--	--	--	--	--	--	--	--	0.793	M	M	M	M	M	M	NR	NR
Chloroform	8.00E+01	MCL	8.00E+01	MCL	4.52E+01	RCRA-VI	8.00E+01	MCL	0.513	**X**	**X**	**X**	**X**	**X**	**X**	NR	NR
Cis-1,2-Dichloroethene	7.00E+01	MCL	7.00E+01	MCL	--	--	--	--	0.864	**X**	**X**	**X**	**X**	**X**	**X**	NR	NR
Ethylbenzene	7.00E+02	MCL	7.00E+02	MCL	2.11E+02	RCRA-VI	7.00E+02	MCL	0.318	M	M	M	M	M	M	NR	NR

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										IPN	Dredge Spoils; Ponds 5-6	Ponds 1-4	DA	DA	DA	Gypsum	Incinerator
										UWBZ			UWBZ			UWBZ	UWBZ
										MPPZ-02AR, MPPZ-03A, MPW-03A, MPW-07AR, MPW-09A, MPW-21A, WCAMW-1A, WCAMW-2A, WCAMW-3A, WCAMW-4A, WCAMW-5A, WCAMW-6A, WCAMW-7A, WCAMW-8A, WCAMW-9A, WCAMW-10A, WCAMW-11A, WCAMW-12A, WCAMW-13A, WCAMW-14A			MPPZ-01A, MPW-01A, MPW-04A, MPW-18A, DAMW-01A, DAMW-02A, DAMW-03A, DAMW-04A, DAMW-05A			PMW-17, GWMW-1A, GWMW-2A, GWMW-3A, GWMW-4A, GWMW-5A, GWMW-6A, GWMW-7A, GWMW-8A, GWMW-9A, GWMW-10A, GWMW-11A	GWMW-12A
										LWBZ			LWBZ			LWBZ	LWBZ
										MPW-21B, M-2BR, MPPZ-02BR, MPPZ-03B, MPW-03B, MPW-07B, WCAMW-1B, WCAMW-2B, WCAMW-3B, WCAMW-4B, WCAMW-5B, WCAMW-6B, WCAMW-7B, WCAMW-8B, WCAMW-9B, WCAMW-10B, WCAMW-11B, WCAMW-12B			MPPZ-01B, MPW-01B, MPW-04B, MPW-18B, DAMW-01B, DAMW-05B			MW-19B, GWMW-1B, GWMW-2B, GWMW-3B, GWMW-4B, GWMW-5B, GWMW-6B, GWMW-7B, GWMW-8B, GWMW-9B, GWMW-10B, GWMW-11B	GWMW-12B
Isopropylbenzene	5.00E-01	HSRA	--	--	--	--	7.82E+01	NC CW	0.5	**X**	**X**	**X**	**X**	**X**	**X**	NR	NR
Methyl Cyclohexane	--	--	--	--	--	--	--	--	2.18	M	M	M	M	M	M	NR	NR
Naphthalene	1.70E-01	RCRA	1.40E+00	NC CW	3.03E+02	RCRA-VI	1.40E+00	NC CW	0.17	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
N-Butylbenzene	--	--	--	--	--	--	--	--	0.322	M	M	M	M	M	M	NR	NR
N-Propylbenzene	--	--	--	--	--	--	--	--	0.423	M	M	M	M	M	M	NR	NR
Sec-Butylbenzene	--	--	--	--	--	--	--	--	0.511	M	M	M	M	M	M	NR	NR
Tert-Butylbenzene	--	--	--	--	--	--	--	--	0.399	M	M	M	M	M	M	NR	NR
Tetrachloroethene (PCE)	5.00E+00	MCL	2.45E+01	NC CW	1.64E+02	RCRA-VI	2.45E+01	NC CW	1	**X**	**X**	**X**	**X**	**X**	**X**	NR	NR
Tetrahydrofuran	--	--	--	--	--	--	--	--	1	M	M	M	M	M	M	NR	NR
Trans-1,2-Dichloroethene	--	--	--	--	--	--	--	--	0.863	M	M	M	M	M	M	NR	NR
Trichloroethene (TCE)	5.00E+00	MCL	5.00E+00	MCL	9.53E+00	RCRA-VI	5.00E+00	MCL	0.844	**X**	**X**	**X**	**X**	**X**	**X**	NR	NR
Vinyl chloride (VC)	2.00E+00	MCL	3.27E+00	HSRA	2.87E+01	RCRA-VI	1.63E+01	NC CW	0.742	**X**	**X**	**X**	**X**	**X**	**X**	NR	NR
Polycyclic Aromatic Hydrocarbon by EPA Method 8270										**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
1-Methylnaphthalene	--	--	--	--	--	--	--	--	0.31	M	M	M	M	M	M	M	M
2-Methylnaphthalene	--	--	--	--	--	--	--	--	0.47	M	M	M	M	M	M	M	M
Acenaphthene	--	--	--	--	--	--	--	--	0.13	M	M	M	M	M	M	M	M
Acenaphthylene	--	--	--	--	--	--	--	--	0.11	M	M	M	M	M	M	M	M
Anthracene	--	--	--	--	--	--	--	--	0.11	M	M	M	M	M	M	M	M
Benzo(a)Anthracene	--	--	--	--	--	--	--	--	0.14	M	M	M	M	M	M	M	M
Benzo(b)Pyrene	2.00E-01	MCL	--	--	--	--	--	--	0.13	**X**	**X**	**X**	**X**	**X**	**X**	**X**	**X**
Benzo(b)Fluoranthene	--	--	--	--	--	--	--	--	0.18	M	M	M	M	M	M	M	M
Benzo(g,h,i)Perylene	--	--	--	--	--	--	--	--	0.16	M	M	M	M	M	M	M	M
Benzo(k)Fluoranthene	--	--	--	--	--	--	--	--	0.16	M	M	M	M	M	M	M	M
Chrysene	--	--	--	--	--	--	--	--	0.16	M	M	M	M	M	M	M	M
Dibenzo(a,h)Anthracene	--	--	--	--	--	--	--	--	0.16	M	M	M	M	M	M	M	M
Fluoranthene	--	--	--	--	--	--	--	--	0.11	M	M	M	M	M	M	M	M
Fluorene	--	--	--	--	--	--	--	--	0.11	M	M	M	M	M	M	M	M
Indeno(1,2,3-cd)Pyrene	--	--	--	--	--	--	--	--	0.18	M	M	M	M	M	M	M	M
Pyrene	--	--	--	--	--	--	--	--	0.13	M	M	M	M	M	M	M	M

Former Tronox Pigments Site

100 SeaPoint Boulevard
Savannah, Chatham County, Georgia
HSI No. 10179
Terracon Project No. ES177321L

TABLE 1: GROUNDWATER MONITORING PROGRAM SUMMARY

Analyte	Groundwater Unrestricted Use Remedial Goal (µg/L)		Non-Residential Groundwater Action Level (µg/L)		RCRA Risk-Based Non-Residential Vapor Intrusion Action Level (µg/L)		RCRA Risk-Based Construction Worker Action Level (µg/L)		Laboratory Detection Limit (µg/L)	Waste Containment Area			Developed Area			Gypsum/Waste Incinerator Area	
										EU-09	EU-10	EU-11	EU-12	EU-13	EU-14	EU-02, EU-03	EU-06
										IPN	Dredge Spoils; Ponds 5-6	Ponds 1-4	DA	DA	DA	Gypsum	Incinerator
										UWBZ			UWBZ			UWBZ	UWBZ
										MPPZ-02AR, MPPZ-03A, MPW-03A, MPW-07AR, MPW-09A, MPW-21A, WCAMW-1A, WCAMW-2A, WCAMW-3A, WCAMW-4A, WCAMW-5A, WCAMW-6A, WCAMW-7A, WCAMW-8A, WCAMW-9A, WCAMW-10A, WCAMW-11A, WCAMW-12A, WCAMW-13A, WCAMW-14A			MPPZ-01A, MPW-01A, MPW-04A, MPW-18A, DAMW-01A, DAMW-02A, DAMW-03A, DAMW-04A, DAMW-05A			PMW-17, GWMW-1A, GWMW-2A, GWMW-3A, GWMW-4A, GWMW-5A, GWMW-6A, GWMW-7A, GWMW-8A, GWMW-9A, GWMW-10A, GWMW-11A	GWMW-12A
										LWBZ			LWBZ			LWBZ	LWBZ
										MPW-21B, M-2BR, MPPZ-02BR, MPPZ-03B, MPW-03B, MPW-07B, WCAMW-1B, WCAMW-2B, WCAMW-3B, WCAMW-4B, WCAMW-5B, WCAMW-6B, WCAMW-7B, WCAMW-8B, WCAMW-9B, WCAMW-10B, WCAMW-11B, WCAMW-12B			MPPZ-01B, MPW-01B, MPW-04B, MPW-18B, DAMW-01B, DAMW-05B			MW-19B, GWMW-1B, GWMW-2B, GWMW-3B, GWMW-4B, GWMW-5B, GWMW-6B, GWMW-7B, GWMW-8B, GWMW-9B, GWMW-10B, GWMW-11B	GWMW-12B
Polychlorinated Biphenyls by EPA Method 8082A													X	X	X		
Aroclor-1248	--	--	--	--	--	--	--	--	0.5	NR	NR	NR	M	M	M	NR	NR
Aroclor-1254	--	--	--	--	--	--	--	--	0.5	NR	NR	NR	M	M	M	NR	NR
Aroclor-1260	--	--	--	--	--	--	--	--	0.5	NR	NR	NR	M	M	M	NR	NR

Note:

µg/L	microgram per liter	NC IW DC	Noncancer Industrial Worker Direct Contact	X	Full suite analytical performed and reported to established screening criteria.
BTV	background threshold value	RCRA	Resource Conservation and Recovery Act	NR	Analyte not collected or reported.
C CW	Cancer Construction Worker	RRS	risk reduction standard	DA	Developed Area
C IW DC	Cancer Industrial Worker Direct Contact	TEQ	toxicity equivalency	M	Parameters will be analyzed in accordance with PPCAP Table 2-23 but do not have established groundwater cleanup goals.
HSRA	Hazardous Site Response Act	VI	vapor intrusion		
MCL	maximum contaminant level	UWBZ	Upper Water Bearing Zone		
NC CW	Noncancer Construction Worker	LWBZ	Lower Water Bearing Zone		

Former Tronox Pigments Site

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HSI No. 10179
Terracon Project No. ES177321L

TABLE 2: UWBZ MONITORING WELL CONSTRUCTION DETAILS AND GROUNDWATER ELEVATIONS

Well Identification	WBZ	Northing	Easting	Ground Elevation (ft)	Top of Casing Elevation (ft)	Top of Screen Depth (ft)	Bottom of Screen Depth (ft)	Measured Total Depth (ft bgs)	Groundwater Elevation (ft)
MPPZ-01A	UWBZ	1007869	759597	8.87	10.96	5	15	17.1	4.58
MPPZ-02A	UWBZ	1009551	760381	9.52	11.89	5	15	17.42	4.63
MPPZ-02AR	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
MPPZ-03A	UWBZ	1010481	758289	7.55	9.63	5	15	17.33	4.4
MPW-01A	UWBZ	1007768	758826	8.51	10.73	5	15	17.29	5.56
MPW-03A	UWBZ	1009574	759737	9.04	11.63	5	15	17.57	6.5
MPW-04A	UWBZ	1008934	758597	7.52	10	5	15	17.41	4.7
MPW-07A	UWBZ	1009345	76082	10.45	12.76	5	15	17.23	6.32
MPPZ-07AR	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
MPW-09A	UWBZ	1009688	759247	9.44	12.12	5	15	17.09	4.05
MPW-18A	UWBZ	1009080	759050	8.9	11.26	5	15	17.35	5.89
MPW-21A	UWBZ	1009878	758574	10.21	11.4	5	15	18.29	10.98
PMW-17	UWBZ	1005368	754662	11.57	13.83	9.2	19.2	21.87	6.18
DAMW-01A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
DAMW-02A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
DAMW-03A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
DAMW-04A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
DAMW-05A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-1A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-2A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-3A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-4A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-5A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-6A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-7A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA

Former Tronox Pigments Site

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Terracon Project No. ES177321L

TABLE 2: UWBZ MONITORING WELL CONSTRUCTION DETAILS AND GROUNDWATER ELEVATIONS

Well Identification	**WBZ**	**Northing**	**Easting**	**Ground Elevation** (ft)	**Top of Casing Elevation** (ft)	**Top of Screen Depth** (ft)	**Bottom of Screen Depth** (ft)	**Measured Total Depth** (ft bgs)	**Groundwater Elevation** (ft)
WCAMW-8A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-9A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-10A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-11A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-12A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-13A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-14A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-1A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-2A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-3A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-4A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-5A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-6A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-7A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-8A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-9A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-10A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-11A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-12A	UWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA

Notes:
a. Measured total depth inconsistent with well construction information
b. NM: Not measured because of transducer malfunction
Vertical measurements presented as elevations are relative to the North American Vertical Datum of 1988 (NAVD 88)
The groundwater elevation averaging was performed from water level measurements collected April 3, 2015 to April 14, 2015

Definitions:

NA - not available	UWBZ - Upper water bearing zone	NA - not applicable	TBD - To Be Determined	bgs - below ground surface
ft - foot/feet	WBZ - water bearing zone		R - Replacement well	MSL - mean sea level

Former Tronox Pigments Site

100 SeaPoint Boulevard
Savannah, Chatham County, Georgia
HSI No. 10179
Terracon Project No. ES177321L

TABLE 3: LWBZ MONITORING WELL CONSTRUCTION DETAILS AND GROUNDWATER ELEVATIONS

Well Identification	WBZ	Northing	Easting	Ground Elevation (ft)	Top of Casing Elevation (ft)	Top of Screen Depth (ft bgs)	Bottom of Screen Depth (ft bgs)	Measured Total Depth (ft bgs)	Groundwater Elevation (ft)
MW-19B	LWBZ	1005355	754660	6.79	6.8	30	40	36.42	1.12
MPPZ-01B	LWBZ	1007869	759597	8.87	11.04	35	40	43.09	1.38
MPW-01B	LWBZ	1007768	758826	8.51	10.64	45	50	52.61	1.23
MPW-03B	LWBZ	1009571	759739	9.04	11.62	35	40	42.85	2.2
MPW-04B	LWBZ	1008934	758597	7.52	10	45	50	52.97	1.86
MPW-21B	LWBZ	1009878	758574	12.5	12.45	41	46	49.37	1.51
M-2B	LWBZ	1010226	760478	8.87	NA	38	44	45.46	-0.44
M-2BR	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
MPPZ-02B	LWBZ	1009551	760382	9.52	12.16	35	40	42.15	2.19
MPPZ-02BR	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
MPPZ-03B	LWBZ	1010481	758291	7.55	9.89	45	50	52.69	2.66
MPW-07B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
MPW-18B	LWBZ	1009080	759050	8.9	10.76	37	42	43.41	1.6
DAMW-01B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
DAMW-05B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-1B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-2B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-3B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-4B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-5B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-6B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-7B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-8B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-9B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-10B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA

Former Tronox Pigments Site

100 SeaPoint Boulevard
Savannah, Chatham County, Georgia
HSI No. 10179
Terracon Project No. ES177321L

TABLE 3: LWBZ MONITORING WELL CONSTRUCTION DETAILS AND GROUNDWATER ELEVATIONS

Well Identification	WBZ	Northing	Easting	Ground Elevation (ft)	Top of Casing Elevation (ft)	Top of Screen Depth (ft bgs)	Bottom of Screen Depth (ft bgs)	Measured Total Depth (ft bgs)	Groundwater Elevation (ft)
WCAMW-11B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
WCAMW-12B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-1B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-2B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-3B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-4B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-5B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-6B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-7B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-8B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-9B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-10B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-11B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
GWMW-12B	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA
LUC-1	LWBZ	TBD	TBD	TBD	TBD	TBD	TBD	TBD	NA

Notes:

a. Measured total depth inconsistent with well construction information

b. NM: Not measured because of transducer malfunction

Vertical measurements presented as elevations are relative to the North American Vertical Datum of 1988 (NAVD 88)

The groundwater elevations were calculated from depth to water measurements collected from April 3, 2015 to April 14, 2015

Definitions:

NA - not available
ft - foot/feet
UWBZ - Upper water bearing zone
WBZ - water bearing zone
NA - not applicable
TBD - To Be Determined
R - Replacement well
bgs - below ground surface
MSL - mean sea level

Former Tronox Pigments Site

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TABLE 4: FIELD PARAMETER STABILIZATION CRITERIA / GOALS FOR MONITORING WELL PURGING AND SAMPLING

Parameter	Low-Flow Method
pH	± 0.1 S.U.
Conductivity	± 5%
Temperature	± 5%
Dissolved Oxygen	± 10% or ± 0.2 mg/L
ORP	± 20 mV
Turbidity	<10 NTU or ± 10%
Drawdown	<0.3 feet
Pumping Rate	100 – 500 mL/min
Volume	No Criteria

Notes:

Low-Flow groundwater sample collection stabilization criteria obtained from USEPA Operating Procedure SESDPROC-301-R4 Groundwater Sampling, dated April 26, 2017.

All Percentages are relative percent difference. Stabilization of the well purge will also be indicated by field parameters showing no increasing or decreasing trends for three successive readings.

Definitions:

S.U. - Standard Units
mg/L - milligrams per liter
mV - millivolts
mL/min - milliliters per minute

Former Tronox Pigments Site

100 SeaPoint Boulevard
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TABLE 5: WELL SEALANT VOLUME ESTIMATES

Diameter of Hole (inch)	**Gallons per Linear Foot**	**Sacks of Cement per Linear Foot**	**Cement Set Volume**
			Linear Feet per Sack
2	0.1632	0.01999	50.2
3	0.3672	0.0311	32.1
4	0.6528	0.0791	12.6
5	1.0200	0.124	8.0
6	1.4688	0.1785	5.6
8	2.6112	0.3373	3.2
10	4.0799	0.4958	2.0
12	5.8752	0.714	1.4

Former Tronox Pigments Site

100 SeaPoint Boulevard
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Terracon Project No. ES177321L

TABLE 6: Preservation Procedures and Holding Times

Parameter	Container Type	Preservative	Holding Time	Volume Required
pH	T,P,G	NA	NA	25 mL
Specific Conductance	T,P,G	NA	NA	100 mL
2,3,7,8-TCDD (Dioxin TEQ)	G, T-lined Cap	Cool to 4°C	30 days	250 mL
Metals	T,P	Total Metals: HNO_3 to pH <2 Dissolved Metals: Field/Lab Filter	6 months	600 mL
Semi-Volatile Organics	G, T-Line Caps	Cool to 4°C	7 days	1,000 mL
Volatile Organics	G, T-Line Caps	Cool to 4°C, HCL to <2 pH No Headspace	14 days	3 Vials X 40 mL
Acrylonitrile	G, T-Line Caps	Cool to 4°C, HCL to <5 pH and >4 pH No Headspace	7 days	3 Vials X 40 mL

Notes:

Preservation procedures and sample holding time obtained from USEPA Hazardous Waste Test Methods for Evaluating Solid Waste: Physical/Chemical Methods (SW-846).

Definitions:

P = Polyethylene
G = Glass
T = Teflon
°C - degrees Celcius
mL - milliliters

APPENDIX C

USEPA Region 4 Field
Standard Operating Procedures

Region 4
U.S. Environmental Protection Agency
Laboratory Services and Applied Science Division
Athens, Georgia

Operating Procedure

Title: Field Equipment Cleaning and Decontamination	ID: LSASDPROC-205-R4
Issuing Authority: LSASD Field Branch Chief	
Effective Date: June 22, 2020	Review Due Date: June 22, 2023

Purpose

This procedure is to be used by Region 4 Laboratory Services and Applied Science Division staff . This document describes general and specific procedures, methods and considerations to be used and observed when cleaning and decontaminating sampling equipment during the course of field investigations. This procedure is to be used by all Region 4 Laboratory Services and Applied Science Division (LSASD) staff.

Scope/Application

The procedures contained in this document are to be followed when field cleaning sampling equipment, for both re-use in the field, as well as used equipment being returned to the Field Equipment Center (FEC). On the occasion that LSASD field investigators determine that any of the procedures described in this section are either inappropriate, inadequate or impractical and that other procedures must be used to clean or decontaminate sampling equipment at a particular site, the variant procedure will be documented in the field logbook, along with a description of the circumstances requiring its use. Mention of trade names or commercial products in this operating procedure does not constitute endorsement or recommendation for use.

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1 General Information

1.1 Documentation/Verification

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

1.2 Definitions

- Decontamination: The process of cleaning dirty sampling equipment to the degree to which it can be re-used, with appropriate QA/QC, in the field.

- Deionized water: Tap water that has been treated by passing through a standard deionizing resin column. At a minimum, the finished water should contain no detectable heavy metals or other inorganic compounds (i.e., at or above analytical detection limits) as defined by a standard inductively coupled Argon Plasma Spectrophotometer (ICP) (or equivalent) scan. Deionized water obtained by other methods is acceptable, as long as it meets the above analytical criteria. Organic-free water may be substituted for deionized water.

- Detergent shall be a standard brand of phosphate-free laboratory detergent such as Liquinox® or Luminox®. Liquinox® is a traditional anionic laboratory detergent and is used for general cleaning and where there is concern for the stability of the cleaned items in harsher cleaners. Luminox® is a specialized detergent with the capability of removing oils and organic contamination. It is used in lieu of a solvent rinse step in cleaning of equipment for trace contaminant sampling. Where not specified in these procedures, either detergent is acceptable.

- Drilling Equipment: All power equipment used to collect surface and sub-surface soil samples or install wells. For purposes of this procedure, direct push is also included in this definition.

- Field Cleaning: The process of cleaning dirty sampling equipment such that it can be returned to the FEC in a condition that will minimize the risk of transfer of contaminants from a site.

- Organic-free water: Tap water that has been treated with activated carbon and deionizing units. At a minimum, the finished water must meet the analytical criteria of deionized water and it should contain no detectable pesticides, herbicides, or extractable organic compounds, and no volatile organic compounds above minimum detectable levels as determined by the Region 4 laboratory for a given set of analyses. Organic-free water obtained by other methods is acceptable, as long as it meets the above analytical criteria.

- Tap water: Water from any potable water supply. Deionized water or organic-free water may be substituted for tap water.

1.3 General Precautions

1.3.1 Safety

Proper safety precautions must be observed when field cleaning or decontaminating dirty sampling equipment. Refer to the LSASD Safety, Health and Environmental Management Program (SHEMP) Procedures and Policy Manual and any pertinent site-specific Health and Safety Plans (HASPs) for guidelines on safety precautions. These guidelines, however, should only be used to complement the judgment of an experienced professional. Address chemicals that pose specific toxicity or safety concerns and follow any other relevant requirements, as appropriate. At a minimum, the following precautions should be taken in the field during these cleaning operations:

- When conducting field cleaning or decontamination using laboratory detergent, safety glasses with splash shields or goggles, and latex gloves will be worn.
- No eating, smoking, drinking, chewing, or any hand to mouth contact should be permitted during cleaning operations.

1.3.2 Procedural Precaution

Prior to mobilization to a site, the expected types of contamination should be evaluated to determine if the field cleaning and decontamination activities will generate rinses and other waste waters that might be considered RCRA hazardous waste or may require special handling.

2 Introduction to Field Equipment Cleaning and Decontamination

2.1 General

The procedures outlined in this document are intended for use by field investigators for cleaning and decontaminating sampling and other equipment in the field. These procedures should be followed in order that equipment is returned to the FEC in a condition that will minimize the risk of transfer of contaminants from a site.

Sampling and field equipment cleaned in accordance with these procedures must meet the minimum requirements for the Data Quality Objectives (DQOs) of the study or investigation. If deviations from these procedures need to be made during the course of the field investigation, they will be documented in the field logbook along with a description of the circumstances requiring the use of the variant procedure.

Cleaning procedures for use at the Field Equipment Center (FEC) are found in LSASD Operating Procedure for Equipment Cleaning and Decontamination at the FEC (LSASDPROC-206).

2.2 Handling Practices and Containers for Cleaning Solutions

Improperly handled cleaning solutions may easily become contaminated. Storage and application containers must be constructed of the proper materials to ensure their integrity. Following are acceptable materials used for containing the specified cleaning solutions:

- Detergent must be kept in clean plastic, metal, or glass containers until used. It should be poured directly from the container during use.

- Tap water may be kept in tanks, hand pressure sprayers, squeeze bottles, or applied directly from a hose.

- Deionized water must be stored in clean, glass or plastic containers that can be closed for transport. It can be applied from plastic squeeze bottles.

- Organic-free water must be stored in clean glass or Teflon® containers prior to use. It may be applied using Teflon® squeeze bottles, or with the portable system.

2.3 Disposal of Cleaning Solutions

Procedures for the safe handling and disposition of investigation derived waste (IDW); including used wash water and rinse water are in LSASD Operating Procedure for Management of Investigation Derived Waste (LSASDPROC-202).

2.4 Sample Collection Equipment Contaminated with Concentrated Materials

Equipment used to collect samples of concentrated materials from investigation sites must be field cleaned before returning from the study. At a minimum, this should consist of washing with detergent and rinsing with tap water. When the above procedure cannot be followed, the following options are acceptable:

- Leave with facility for proper disposal;

- If possible, containerize, seal, and secure the equipment and leave on-site for later disposal;

- Containerize, bag, or seal the equipment so that no odor is detected and return to the Field Equipment Center.

It is the project leader's responsibility to evaluate the nature of the sampled material and determine the most appropriate cleaning procedures for the equipment used to sample that material.

2.5 Sample Collection Equipment Contaminated with Environmental Media

Equipment used to collect samples of environmental media from investigation sites should be field cleaned before returning from the study. Based on the condition of the sampling equipment, one or more of the following options must be used for field cleaning:

- Wipe the equipment clean;

- Water-rinse the equipment;

- Wash the equipment in detergent and water followed by a tap water rinse.

- For grossly contaminated equipment, the procedures set forth in Section 2.4 must be followed.

Under extenuating circumstances such as facility limitations, regulatory limitations, or during residential sampling investigations where field cleaning operations are not feasible, equipment can be containerized, bagged or sealed so that no odor is detected and returned to the FEC without being field cleaned. If possible, FEC personnel should be notified that equipment will be returned without being field cleaned. It is the project leader's responsibility to evaluate the nature of the sampled material and determine the most appropriate cleaning procedures for the equipment used to sample that material.

2.6 Handling of Decontaminated Equipment

After decontamination, equipment should be handled only by personnel wearing clean gloves to prevent re-contamination. In addition, the equipment should be moved away (preferably upwind) from the decontamination area to prevent re-contamination. If the equipment is not to be immediately re-used, it should be covered with plastic sheeting or wrapped in aluminum foil to prevent re-contamination. The area where the equipment is kept prior to re-use must be free of contaminants.

3 Field Equipment Decontamination Procedures

3.1 General

Sufficient equipment should be transported to the field so that an entire study can be conducted without the need for decontamination. When equipment must be decontaminated in the field, the following procedures are to be utilized.

Note: Equipment utilized for PFAS sampling will not cleaned in the field.

3.2 Specifications for Decontamination Pads

Decontamination pads constructed for field cleaning of sampling and drilling equipment should meet the following minimum specifications:

- The pad should be constructed in an area known or believed to be free of surface contamination.
- The pad should not leak.
- If possible, the pad should be constructed on a level, paved surface and should facilitate the removal of wastewater. This may be accomplished by either constructing the pad with one corner lower than the rest, or by creating a sump or pit in one corner or along one side. Any sump or pit should also be lined.
- Sawhorses or racks constructed to hold equipment while being cleaned should be high enough above ground to prevent equipment from being splashed.
- Water should be removed from the decontamination pad frequently.
- A temporary pad should be lined with a water impermeable material with no seams within the pad. This material should be either easily replaced (disposable) or repairable.

At the completion of site activities, the decontamination pad should be deactivated. The pit or sump should be backfilled with the appropriate material designated by the site project leader, but only after all waste/rinse water has been pumped into containers for disposal. See LSASD Operating Procedure for Management of Investigation Derived Waste (LSASDPROC-202) for proper handling and disposal of these materials. If the decontamination pad has leaked excessively, soil sampling may be required.

3.3 "Classical Parameter" Sampling Equipment

"Classical Parameters" are analyses such as oxygen demand, nutrients, certain inorganic compounds, sulfide, flow measurements, etc. For routine operations involving classical parameter analyses, water quality sampling equipment such as Kemmerers, buckets, dissolved oxygen dunkers, dredges, etc., may be cleaned with the sample water or tap water between sampling locations as appropriate.

Flow measuring equipment such as weirs, staff gages, velocity meters, and other stream gauging equipment may be cleaned with tap water between measuring locations, if necessary.

Note: The procedures described in Section 3.3 are not to be used for cleaning field equipment to be used for the collection of samples undergoing trace organic or inorganic constituent analyses.

3.4 Sampling Equipment used for the Collection of Trace Organic and Inorganic Compounds

For samples undergoing trace organic or inorganic constituent analyses, the following procedures are to be used for all sampling equipment or components of equipment that come in contact with the sample:

3.4.1 Standard LSASD Method

- An optional Liquinox® detergent wash step may be useful to remove gross dirt and soil.
- Clean with tap water and Luminox® detergent using a brush, if necessary, to remove particulate matter and surface films.
- Rinse thoroughly with tap water.
- Rinse thoroughly with organic-free water and place on a clean foil-wrapped surface to **a**ir-dry.
- Wrap the dry equipment with aluminum foil or bag in clean plastic. If the equipment is to be stored overnight before it is wrapped in foil, it should be covered and secured with clean, unused plastic sheeting.

3.4.2 Alternative Solvent Rinse Method

The historical solvent rinse method of cleaning equipment for trace contaminant sampling remains an acceptable method.

- Clean with tap water and Liquinox® detergent using a brush, if necessary, to remove particulate matter and surface films. Equipment may be steam cleaned (Liquinox® detergent and high-pressure hot water) as an alternative to brushing. Sampling equipment that is steam cleaned should be placed on racks or saw horses at least two feet above the floor of the decontamination pad. PVC or plastic items should not be steam cleaned.

- Rinse thoroughly with tap water.

- Rinse thoroughly with deionized water.
- Rinse with an appropriate solvent (generally isopropanol).
- Rinse with organic-free water and place on a clean foil-wrapped surface to **a**ir-dry.
- Wrap the dry equipment with aluminum foil or plastic. If the equipment is to be stored overnight before it is wrapped, it should be covered and secured with clean, unused plastic sheeting.

3.5 Well Sounders or Tapes

The following procedures are recommended for decontaminating well sounders (water level indicators) and tapes. Unless conditions warrant, it is only necessary to decontaminate the wetted portion of the sounder or tape.

- Wash with Liquinox® detergent and tap water.
- Rinse with tap water.
- Rinse with deionized water.

3.6 Redi-Flo2® Pump

CAUTION – Do not wet the controller. Always disconnect power from the pump when handling the pump body.

The Redi-Flo2® pump and any associated connected hardware (e.g., check valve) should be decontaminated between each monitoring well. The following procedures are required, depending on whether the pump is used solely for purging or used for purging and sampling.

3.6.1 Purge Only (Pump and Wetted Portion of Tubing or Hose)

- Disconnect power and wash exterior of pump and wetted portion of the power lead and tubing or hose with Liquinox® detergent and water solution.
- Rinse with tap water.
- Final rinse with deionized water.
- Place pump and reel in a clean plastic bag and keep tubing or hose contained in clean plastic or galvanized tub between uses.

3.6.2 Purge And Sample

Grundfos Redi-Flo2® pumps are extensively decontaminated and tested at the FEC to prevent contamination from being transmitted between sites. The relevant sections of LSASDPROC-206, *Field Equipment Cleaning and Decontamination at the FEC,* should be implemented in the field where a high risk of cross-contamination exists, such as where NAPL or high-concentration contaminants occur. In most cases, the abbreviated cleaning procedure described below will suffice, provided that sampling proceeds from least to most contaminated areas.

- Disconnect and discard the previously used sample tubing from the pump. Remove the check valve and tubing adapters and clean separately (See Section 3.6.3 for check valve). Wash the pump exterior with detergent and water.

- Prepare and fill three containers with decontamination solutions, consisting of Container #1, a tap water/detergent washing solution. Luminox® is commonly used. An additional pre-wash container of Liquinox® may be used; Container #2, a tap water rinsing solution; and Container #3, a deionized or organic-free water final rinsing solution. Choice of detergent and final rinsing solution for all steps in this procedure is dependent upon project objectives (analytes and compounds of interest). The containers should be large enough to hold the pump and one to two liters of solution. An array of 2' long 2" PVC pipes with bottom caps is a common arrangement. The solutions should be changed at least daily.

- Place the pump in Container #1. Turn the pump on and circulate the detergent and water solution through the pump and then turn the pump off.

- Place the pump in Container #2. Turn the pump on and circulate the tap water through the pump and then turn the pump off.

- Place the pump in Container #3. Turn the pump on and circulate deionized or organic-free water through the pump and then turn the pump off.

- Disconnect power and remove pump from Container #3. Rinse exterior and interior of pump with fresh deionized or organic-free water.

- Decontaminate the power lead by washing with detergent and water, followed by tap water and deionized water rinses. This step may be performed before washing the pump if desired.

- Reassemble check valve and tubing adapters to pump. ALWAYS use Teflon® tape to prevent galling of threads. Firm hand-tightening of fittings or light wrench torque is generally adequate.

- Place the pump and reel in a clean plastic bag.

3.6.3 Redi-Flo2® Ball Check Valve

- Remove the ball check valve from the pump head. Check for wear and/or corrosion, and replace as needed. During decontamination check for free-flow in forward direction and blocking of flow in reverse direction.

- Using a brush, scrub all components with detergent and tap water.

- Rinse with deionized water.

- Rethread the ball check valve to the Redi-Flo2® pump head.

3.7 Mega-Monsoon® and GeoSub® Electric Submersible Pump

As these pumps have lower velocities in the turbine section and are easier to disassemble in the field than Grundfos pumps, the outer pump housing should be removed to expose the impeller for cleaning prior to use and between each use when used as a sampling pump for trace contaminant sampling.

- Remove check valves and adapter fittings and clean separately.
- Remove the outer motor housing by holding the top of the pump head and unscrewing the outer housing from its O-ring sealed seat.
- Clean all pump components per the provisions of section 3.4. Use a small bottle brush for the pump head passages
- Wet the O-ring(s) on the pump head with organic-free water. Reassemble the outer pump housing to the pump head.
- Clean cable and reel per Section 3.4.
- Conduct final rinse of pump with organic-free water over pump and through pump turbine.

3.8 Bladder Pumps

Bladder pumps are presumed to be intended for use as low flow purge-and-sample pumps. The Geotech® bladder pump and Geoprobe Systems® mechanical bladder pump can be cleaned similarly.

- Discard any tubing returned with the pump.

- Completely disassemble the pump, being careful to note the initial position of and retain any springs and loose ball checks.

- Discard pump bladder.

- Clean all parts as per the standard cleaning procedure in Section 3.4.

- Install a new Teflon® bladder and reassemble pump.

3.9 Downhole Drilling Equipment

While LSASD does not currently operate drilling equipment, LSASD personnel do oversee and specify drilling operations. The following procedures are to be used for drilling activities involving the collection of soil samples for trace organic and inorganic constituent analyses and for the construction of monitoring wells to be used for the collection of groundwater samples for trace organic and inorganic constituent analyses.

3.9.1 Introduction

Cleaning and decontamination of all equipment should occur at a designated area (decontamination pad) on the site. The decontamination pad should meet the specifications of Section 3.2 of this procedure.

Tap water brought on the site for drilling and cleaning purposes should be contained in a pre-cleaned tank.

A steam cleaner and/or high pressure hot water washer capable of generating a pressure of at least 2500 PSI and producing hot water and/or steam, with a detergent compartment, should be obtained.

3.9.2 Preliminary Cleaning and Inspection

Drilling equipment should be clean of any contaminants that may have been transported from off-site to minimize the potential for cross-contamination. The drilling equipment should not serve as a source of contaminants. Associated drilling and decontamination equipment, well construction materials, and equipment handling procedures should meet these minimum specified criteria:

- All downhole augering, drilling, and sampling equipment should be sandblasted before use if painted, and/or there is a buildup of rust, hard or caked matter, etc., that cannot be removed by steam cleaning (detergent and high pressure hot water), or wire brushing. Sandblasting should be performed prior to arrival on site, or well away from the decontamination pad and areas to be sampled.

- Any portion of the drilling equipment that is over the borehole (kelly bar or mast, backhoe buckets, drilling platform, hoist or chain pulldowns, spindles, cathead, etc.) should be steam cleaned (detergent and high pressure hot water) and wire brushed (as needed) to remove all rust, soil, and other material which may have come from other sites before being brought on site.

- Printing and/or writing on well casing, tremie tubing, etc., should be removed before use. Emery cloth or sand paper can be used to remove the printing and/or writing. Most well material suppliers can provide materials without the printing and/or writing if specified when ordered. Items that cannot be cleaned are not acceptable and should be discarded.

- Equipment associated with the drilling and sampling activities should be inspected to insure that all oils, greases, hydraulic fluids, etc., have been removed, and all seals and gaskets are intact with no fluid leaks.

3.9.3 Drill Rig Field Cleaning Procedure

Any portion of the drill rig, backhoe, etc., that is over the borehole (kelly bar or mast, backhoe buckets, drilling platform, hoist or chain pulldowns, spindles, cathead, etc.) should be steam cleaned (detergent and high pressure hot water) between boreholes.

3.9.4 Field Decontamination Procedure for Drilling Equipment

The following is the standard procedure for field cleaning augers, drill stems, rods, tools, and associated equipment. This procedure does not apply to well casings, well screens, or split-spoon samplers used to obtain samples for chemical analyses, which should be decontaminated as outlined in Section 3.4 of this procedure.

- Wash with tap water and detergent, using a brush if necessary, to remove particulate matter and surface films. Steam cleaning (high pressure hot water with detergent) may be necessary to remove matter that is difficult to remove with the brush. Drilling equipment that is steam cleaned should be placed on racks or saw horses at least two feet above the floor of the decontamination pad. Hollow-stem augers, drill rods, etc., that are hollow or have holes that transmit water or drilling fluids, should be cleaned on the inside with vigorous brushing.

- Rinse thoroughly with tap water.

- Remove from the decontamination pad and cover with clean, unused plastic if not used immediately. If stored overnight, the plastic should be secured to ensure that it stays in place.

3.9.5 Field Decontamination Procedure for Direct Push Technology (DPT) Equipment

- Certain specific procedures for the decontamination of DPT tools are described in the various sampling procedures, but the following general guidelines apply:

- Prior to return to the Field Equipment Center, all threaded tool joints should be broken apart and the equipment cleaned per the provisions of *Section 2.5, Sample Collection Equipment Contaminated with Environmental Media* of this procedure.

- Equipment that contacts the sample media and is cleaned in the field for reuse should be cleaned per the provisions of *Section 3.4, Sampling Equipment used for the Collection of Trace Organic and Inorganic Compounds* of this procedure. This would include piston sampler points and shoes, screen point sampler screens and sheaths, and the drive rods when used for groundwater sampling.

- Equipment that does not directly contact the sample media and is cleaned in the field for reuse can generally be cleaned per the provisions of Section *3.7.4, Field Decontamination Procedure for Drilling Equipment* of this procedure.

- Stainless steel SP15/16 well screens require special care as the narrow slots are difficult to clean under even controlled circumstances and galvanic corrosion can release chrome from the screen surface. As soon as possible after retrieval, the screen slots should be sprayed from the outside to break loose as much material as possible before it can dry in place. To prevent galvanic corrosion, the screens must be segregated from the sampler sheaths, drive rods, and other carbon steel during return transport from the field.

3.10 Rental Pumps

Completing a groundwater sampling project may require the use of rental pumps. Rental pumps are acceptable where they are of suitable stainless steel and Teflon® construction. These pumps should be cleaned prior to use using the procedures specified herein and a rinse-blank collected prior to use.

4 References

LSASD Operating Procedure for Management of Investigation Derived Waste, LSASDPROC-202, Most Recent Version

LSASD Operating Procedure for Equipment Cleaning and Decontamination at the FEC, LSASDPROC-206, Most Recent Version

US EPA. Safety, Health and Environmental Management Program Procedures and Policy Manual. Region 4 LSASD, Athens, GA, Most Recent Version

Revision History

The top row of this table shows the most recent changes to this controlled document. For previous revision history information, archived versions of this document are maintained by the LSASD Document Control Coordinator on the LSASD local area network (LAN).

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LSASDPROC-205-R4, *Field Equipment Cleaning and Decontamination,* replaces SESDPROC-205-R3 **General:** Updated format, Division and Branch names and naming conventions post agency re-alignment. Section 3.1: Added note that PFAS sampling equipment will not be cleaned in the field. Clarified in Section 3.9 that LSASD does not performing drilling activities.	June 22, 2020
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SESDPROC-205-R1, *Field Equipment Cleaning and Decontamination*, replaces SESDPROC-205-R0.	November 1, 2007

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Region 4
U.S. Environmental Protection Agency
Science and Ecosystem Support Division
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GUIDANCE

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SESDGUID-101-R0, *Design and Installation of Monitoring Wells*, Original Issue	February 18, 2008

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1 General Information

1.1 Purpose

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

1.2 Scope/Application

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

1.3 Documentation/Verification

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

1.4 References

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

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

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

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

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

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

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

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

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

1.5 General Precautions

1.5.1 Safety

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

1.5.2 Procedural Precautions

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

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

2 Permanent Monitoring Well Design Considerations

2.1 General

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

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

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

2.2 Drilling Methods

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

2.2.1 Hollow Stem Auger (HSA)

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

2.2.2 Solid Stem Auger

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

Both of the previously discussed auger methods can be used in unconsolidated soils and semi-consolidated (weathered rock) soils, but not in competent rock.

Each method can be employed without introducing foreign materials into the borehole such as water and drilling fluids, minimizing the potential for cross contamination. Minimizing the risk of cross contamination is one of the most important factors to consider when selecting the appropriate drilling method(s) for a project.

2.2.3 Sonic Methods

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

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

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

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

2.2.4 Rotary Methods

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

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

2.2.4.1 Water Rotary

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

2.2.4.2 Air Rotary

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

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

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

2.2.4.3 Mud Rotary

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

2.2.5 Other Methods

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

2.3 Borehole Construction

2.3.1 Annular Space

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

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

2.3.2 Over-drilling the Borehole

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

2.3.3 Filter Pack Placement

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

2.3.4 Filter Pack Seal – Bentonite Pellet Seal (Plug)

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

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

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

2.3.5 Grouting the Annular Space

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

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

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

2.3.6 Above Ground Riser Pipe and Outer Casing

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

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

2.3.7 Concrete Surface Pad

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

2.3.8 Surface Protection – Bumper Guards

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

2.4 Construction Techniques

2.4.1 Well Installation

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

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

No lubricating oils or grease should be used on casing threads. No glue of any type should be used to secure casing joints. Teflon "O" rings can also be used to insure a tight fit and minimize leakage; however, "O" rings made of other materials are not acceptable if the well is going to be sampled for organic compound analyses.

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

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

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

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

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

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

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

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

2.4.2 Double-Cased Wells

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

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

2.4.2.1 Bedrock Wells

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

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

applicable. When the drilling is complete, the finished well will consist of an open borehole from the ground surface to the bottom of the well. There is no inner casing, and the outer surface casing, installed down into bedrock, extends above the ground surface, and also serves as the outer protective casing. If the protective casing becomes cracked or is sheared off at the ground surface, the well is open to direct contamination from the ground surface and will have to be repaired immediately or abandoned. Another limitation to the open rock well is that the entire bedrock interval serves as the monitoring zone. In this situation, it is very difficult or even impossible to monitor a specific zone, because the contaminants being monitored could be diluted to the extent of being non-detectable. The installation of open bedrock wells is generally not acceptable in the Superfund and RCRA programs, because of the uncontrolled monitoring intervals. However, some site conditions might exist, especially in cavernous limestone areas (karst topography) or in areas of highly fractured bedrock, where the installation of the filter pack and its structural integrity are questionable. Under these conditions the design of an open bedrock well may be warranted.

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

2.5 Well Construction Materials

2.5.1 Introduction

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

2.5.2 Well Screen and Casing Materials

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

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

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

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

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

2.5.3 Filter Pack Materials

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

2.5.4 Filter Pack and Well Screen Design

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

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

Aquifers, may be consulted for further guidance on specifications for sand appropriate for these applications.

Table 6.6.1
Sand Pack Specifications

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

The following procedure should be used in coarser grained formations:

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

$$Cu = (d60/d10)$$

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

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

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

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

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

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

Steps to design a filter pack in aquifers:

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

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

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

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

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

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

2.6 Safety Procedures for Drilling Activities

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

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

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

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

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

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

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

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

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

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

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

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

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

2.7 Well Development

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

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

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

These development procedures can be used, individually or in combination, in order to achieve the most effective well development. In most cases, over-pumping and surging will adequately develop the well without imparting undue forces on the formation or well materials. Except when compressed air is being used for well development, sampling can be initiated as soon as the ground water has re-equilibrated, is free of visible sediment, and the water quality parameters have stabilized. Since site conditions vary, even between wells, a general rule-of-thumb is to wait 24 hours after development to sample a new monitoring well. Wells developed with stressful measures may require as long as a 7-day interval before sampling. In particular, air surge developed wells require 48 hours or longer after development so that the formation can dispel the compressed air and re-stabilize to pre-well construction conditions. Because of the danger of introducing contaminants with the airstream, the possibility of entraining air in the aquifer, and the violent forces imparted to the formation, air surging is the least desired method of development and should only be used where there is a specific need for the procedure. Air-lift pumping is permissible where an eductor pipe is used and several well volumes of water are removed from the well by other by pumping means after air-lift pumping. The selected development method(s) should be approved by a senior field geologist before any well installation activities are initiated.

2.8 Well Decommisioning (Abandonment)

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

2.8.1 Decommissioning Procedures

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

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

Where state regulations and conditions permit, it may be permissible to grout the casing in place. This decision should be based on confidence in the original well construction practice, protection of drinking water aquifers, and anticipated future property uses. The pad should be demolished and the area around the casing excavated. The casing should be sawn off at a depth of three feet below ground surface. The screen and riser should be tremie grouted with a 30% solids bentonite grout in the saturated zone. The remaining riser may be grouted with a cement grout for long term resistance to desiccation.

3 Temporary Monitoring Well Installation

3.1 Introduction

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

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

Due to the nature of construction, turbidity levels may initially be high. However, these levels may be reduced by low flow purging and sampling techniques as described in Section 7.2.4.

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

3.2 Data Limitation

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

3.3 Temporary Well Materials

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

3.4 Temporary Monitoring Well Borehole Construction

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

3.5 Temporary Monitoring Well Types

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

3.5.1 No Filter Pack

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

3.5.2 Inner Filter Pack

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

3.5.3 Traditional Filter Pack

For this type of well, the screen and casing are inserted into the borehole, and the sand is poured into the annular space surrounding the screen and casing. Occasionally, it may be difficult to effectively place a filter pack around shallow open boreholes, due to collapse. This method requires more sand than the "inner filter pack" well, increasing material costs. As the filter pack is placed, it mixes with the muddy water in the borehole, which may increase the amount of time needed to purge the well to an acceptable level of turbidity.

3.5.4 Double Filter Pack

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

3.5.5 Well-in-a-Well

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

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

3.6 Decommissioning

Temporary well boreholes must be decommissioned after sampling and removal of the screen and riser. Backfilling the holes with cuttings may be acceptable practice for shallow holes in uniform materials with expected low contamination levels. Use of cuttings would not be an acceptable practice if waste materials were encountered or a confining layer was breached. Likewise, where the borehole is adjacent to, or downgradient of contaminated areas, the loose backfilled material could create a highly permeable conduit for contaminant migration. If the borehole will not be backfilled with the soil cuttings for this or other reasons, then SESD Operating Procedure for Management of Investigation Derived Waste, SESDPROC-202, should be referenced regarding disposal of the cuttings as IDW.

4 Temporary Monitoring Well Installation Using the Geoprobe® Screen Point 15/16 Groundwater Sampler

4.1 Introduction

The Geoprobe® Screen Point 15/16 Groundwater Sampler is a discrete interval ground water sampling device that can be pushed to pre-selected sampling depths in saturated, unconsolidated materials. Once the target depth has been reached, the screen is opened and groundwater can be sampled as a temporary monitoring well, which yields a representative, uncompromised sample from that depth. Using knock-out plugs, this method also allows for grouting of the push hole during sample tool retrieval.

The Screen Point® 15 sampler consist of four parts (drive point, screen, sampler sheath and drive head), with an assembled length of 52 inches (1321 mm) and a maximum OD of 1.5 inches (38 mm). When opened, it has an exposed screen length of 41 inches (1041 mm). It is typically pushed using 1.25-inch probe rod. The Screen Point® 16 consists of the same parts and works in the same fashion, the only differences being larger diameter and its use with 1.5" rods.

4.1.1 Assembly of Screen Point® 15/16 Groundwater Sampler

1. Install O-ring on expendable point and firmly seat in the angled end of the sampler sheath.

2. Place a grout plug in the lower end of the screen section. Grout plug material should be chosen with consideration for site specific Data Quality Objectives (DQOs).

3. When using stainless steel screen, place another O-ring* in the groove on the upper end of the screen and slide it into the sampler sheath.

4. Place an O-ring* on the bottom of the drive head and thread into the top of the sampler sheath.

5. The Screen Point® 15/16 Groundwater Sampler is now assembled and ready to push for sample collection.

* It should be noted that O-ring use in steps 3 and 4 are optional.

4.1.2 Installation of Screen Point® 15/16 Groundwater Sampler

1. Attach drive cap to top of sampler and slowly drive it into the ground. Raise the hammer assembly, remove the drive cap and place an O-ring* in the top groove of the drive head. Add a probe rod and continue to push the rod string.

2. Continue to add probe rods until the desired sampling depth is reached.

3. When the desired sampling depth is reached, re-position the probe derrick and position either the casing puller assembly or the rod grip puller over the top of the top probe rod.

4. Thread a screen push adapter on an extension rod and attach sufficient additional extension rods to reach the top of the Screen Point® 15/16 sampler. Add an extension handle to the top of the string of extension rods and run this into the probe rod, resting the screen push adapter on top of the sampler.

5. To expose the screened portion of the sampler, exert downward pressure on the sampler, using the extension rod and push adapter, while pulling the probe rod upward. To expose the entire open portion of the screen, pull the probe rod upward approximately 41 inches.

6. At this point, the Screen Point® 15/16 Groundwater Sampler has been installed as a temporary well and may be sampled using appropriate ground water sampling methodology. If waters levels are less than approximately 25 feet, EIB personnel typically use a peristaltic pump, utilizing low-flow methods, to collect ground water samples from these installations. If water levels are greater than 25 feet, a manual bladder pump, a micro bailer, or other method may have to be utilized to collect the sample (SESD Operating Procedure for Groundwater Sampling, SESDPROC-301-R0) provides detailed descriptions of these techniques and methods).

4.1.3 Special Considerations for Screen Point® 15/16 Installations

Decommissioning (Abandonment)

In many applications, it may be appropriate to grout the abandoned probe hole where a Screen Point® 15/16 sampler was installed. This probe hole decommissioning can be accomplished through two methods which are determined by location and contamination risk. In certain non-critical areas, boreholes may be decommissioned by filling the saturated zone with bentonite pellets and grouting the vadose zone with neat cement poured from the surface or Bentonite pellets properly hydrated in place. Probe holes in areas where poor borehole sealing could present a risk of contaminant migration should be decommissioned by pressure grouting through the probe rod during sampler retrieval. To accomplish this, the grout plug is knocked out of the bottom of the screen using a grout plug push adapter and a grout nozzle is fed through the probe rod, extending just below the bottom of the screen. As the probe rod and sampler are pulled, grout is injected in the open hole below the screen at a rate that just fills the open hole created by the pull. Alternatively, the screen can generally be pulled and the hole re-probed with a tool string to be used for through-the-rod grouting.

Screen Material Selection

Screen selection is also a consideration in sampling with the Screen Point® 15/16 sampler. The screens are available in two materials, stainless steel and PVC. Because of stainless steel's durability, ability to be cleaned and re-used, and overall inertness and compatibility with most contaminants, it is the material typically used during EIB investigations.

Region 4
U.S. Environmental Protection Agency
Science and Ecosystem Support Division
Athens, Georgia

OPERATING PROCEDURE

Title: **Field Measurement of Dissolved Oxygen**

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The top row of this table shows the most recent changes to this controlled document. For previous revision history information, archived versions of this document are maintained by the SESD Document Control Coordinator on the SESD local area network (LAN).

History	Effective Date
SESDPROC-106-R4, *Field Measurement of Dissolved Oxygen*, replaces SESDPROC-106-R3 **General:** Corrected any typographical, grammatical, and/or editorial errors. In addition, any references to former Division organizational structure was updated to reflect current structure. **Title Page:** Changed the Author from Hunter Johnson to Nathan Barlet. Changed the Field Quality Manager from Bobby Lewis to Hunter Johnson. Updated cover page to represent SESD reorganization. **Table of Contents:** Added Sections 3.2.1 Water-Saturated Air Method, 3.2.2 Air-Saturated Water Method, and 3.2.3 Zero-DO Verification & 2-Point Calibration. Changed Section 3.5 from "Operational Check" to "Operational Verification." Updated page numbers. **Section 1.4:** Added the citations for Benson and Krause (1980), Benson and Krause (1984), USGS (2013*a*), and USGS (2013*b*) as references, **Section 3.1:** Changed "volume of oxygen contained in a volume of water" to "mass of molecular oxygen contained in a volume of water." Changed "pressure" in first paragraph and third bullet point to "atmospheric pressure." **Section 3.2:** Added "However, some optical DO meters are capable of a two-point calibration at 0% and 100% saturation, refer to Section 3.2.3 for applicability." Added Section 3.2.1 Water-Saturated Air Method, which includes information on the calibration procedure for the water-saturated air method. Added "Allow at least 10-15 minutes for the temperature and dissolved oxygen readings to equilibrate. Ensure that water droplets are removed from the luminescence cap or Clark cell membrane and thermistor before calibration. Refer to Section 3.5 for calibration verification procedure." Added Section 3.2.2 Air-Saturated Water Method, which includes information on the calibration procedure for the air-saturated water	April 12, 2017

method. Added “Refer to Section 3.5 for calibration verification procedure.” Added Section 3.2.3 Zero-DO Verification & 2-Point Calibration. Added “It is recommended that a zero-DO verification is conducted periodically or when concentrations are expected to be below 1 mg/l (USGS, 2013*a*). A zero-DO solution can be prepared by dissolving 1 gram of sodium sulfite in 1 liter of deionized water. This should be made fresh weekly or as needed. If the unit is equipped with a wiper, it should be removed before immersing in zero-DO solution. The reading should not exceed a concentration of 0.2 mg/l dissolved oxygen in the zero-DO solution. For Clark cells that exceed this concentration, replace the electrolyte and membrane before repeating the zero-DO verification process. For optical probes that read above 0.2 mg/l in zero-DO solution, replace the sensor cap if it is expired or perform a 2-point calibration if applicable. Some optical DO probes are capable of 2-point calibrations using a zero-DO solution and the air-saturated water method discussed in Section 3.2.2. Refer to the manufacturer’s instruction manual for the appropriate 2-point calibration procedure. Ensure that the probe is thoroughly rinsed of zero-DO solution after verification or calibration to avoid measurement interferences caused by residual sodium sulfite.” **Section 3.4:** Changed the fifth bullet point to read “The DO meter should be capable of auto-correcting for specific conductivity/salinity or a separate instrument should be used to measure specific conductivity/salinity so that the final DO measurement(s) can be corrected.” **Section 3.5:** Changed the title from “Operational Check” to “Operational Verification.” Changed first paragraph to read “A post-calibration and post-operation instrument verification check should be performed using one of the techniques described in Sections 3.2.1 and 3.2.2 or 3.2.3 (for 2-point calibrations) to quantify potential instrument drift during use. A verification check will be performed after a calibration and at the end of all measurements” Changed second paragraph to read “It may be appropriate to verify the calibration of a DO meter periodically during the course of a day’s measurements when conducting individual measurements. A DO probe may be re-calibrated throughout the day if drift is occurring. The verification DO concentration should be measured and recorded in the field logbook prior to any instrument adjustment.” Also added the sentence “For long-term deployments a post-operation verification should be performed at the end of the deployment.” Added third paragraph which reads “Verification is done by comparing a post-calibration or post-operation reading at 100% saturation conditions to a DO solubility table value at the ambient air/water	

temperature and barometric pressure. Post-calibration and post-operation readings should not exceed a maximum of ± 0.2 mg/l from the DO solubility table value. DO solubility tables can be accessed via the U.S. Geological Survey's DOTABLES software (USGS, 2013*b*) which are based on equations from Benson and Krause (1980; 1984)."	
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1 General Information

1.1 Purpose

This document describes methods and considerations to be used and observed when conducting field measurements of dissolved oxygen in surface water, treated wastewater and in gas media for specific applications (e.g., reaeration measurement).

1.2 Scope/Application

On the occasion that SESD field investigators determine that any of the procedures described in this section are inappropriate, inadequate or impractical and that another method must be used to obtain a measurement of dissolved oxygen, the alternate procedure will be documented in the field log book, along with a description of the circumstances requiring its use. Mention of trade names or commercial products in this operating procedure does not constitute endorsement or recommendation for use.

1.3 Documentation/Verification

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

1.4 References

Benson, B.B., and Krause, D., Jr, 1980. The concentration and isotopic fractionation of gases dissolved in freshwater in equilibrium with the atmosphere—1. Oxygen: Limnology and Oceanography, v. 25, no. 4, p. 662–671.

Benson, B.B., and Krause, D., Jr, 1984. The concentration and isotopic fractionation of oxygen dissolved in freshwater and seawater in equilibrium with the atmosphere: Limnology and Oceanography, v. 29, no. 3, p. 620–632.

SESD Operating Procedure for Equipment Inventory and Management, SESDPROC-108, Most Recent Version

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

SESD Field Branches Quality Management Plan, SESDPLAN-001, Most Recent Version

USEPA. Safety, Health and Environmental Management Program Procedures and Policy Manual. Region 4 SESD, Athens, GA, Most Recent Version

USGS, 2013*a*. Dissolved Oxygen (ver. 3.0): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, sec. 6.2, *http://water.usgs.gov/owq/FieldManual/Chapter*6/6.2_v3.0.pdf.

USGS, 2013*b*. DOTABLES (ver. 3.5): Dissolved Oxygen Solubility Tables, *https://water.usgs.gov/software/DOTABLES/*.

1.5 General Precautions

1.5.1 Safety

Refer to the SESD Safety, Health and Environmental Management Program Procedures and Policy Manual and any pertinent site-specific Health and Safety Plans (HASPs) for guidelines on safety precautions. These guidelines, however, should only be used to complement the judgment of an experienced professional. When using this procedure, minimize exposure to potential health hazards through the use of protective clothing, eye wear and gloves. Address chemicals that pose specific toxicity or safety concerns and follow any other relevant requirements, as appropriate.

Appropriate precautions should be observed when working in and around bodies of water and on boats. Be aware of fast flowing waters, waterway obstructions such as dams, and other vessels on the water.

2 Quality Control

All dissolved oxygen meters will be maintained and operated in accordance with the manufacturer's instructions and the SESD Operating Procedure for Equipment Inventory and Management (SESDPROC-108). Before a meter is utilized in the field, it will be calibrated and verified, according to Section 3.2 of this procedure, to ensure it is operating properly. These calibration and verification checks will be documented and maintained in a logbook.

For in-situ measurements, an instrument warm-up period appropriate for that instrument should be provided. Consult manufacturer's documentation for appropriate warm-up time.

The ambient temperature in the immediate vicinity of the meter should be measured and recorded in the field logbook to insure the instrument is operated within the manufacturer's specified range of operating temperatures. For instruments that are deployed for in-situ measurements, the temperature of the medium being monitored should be measured and recorded in the logbook prior to deployment. *In-situ monitoring equipment may be utilized in unattended deployments where autonomous logging may preclude temperature measurement prior to deployment. Because in situ instrumentation generally has a wide range of operating temperature, the field investigator may utilize professional judgment in determining if the operating environment is suitable for unattended deployment.*

Following instrument use, an end check should be performed using one of the techniques described in Section 3.2 to quantify potential instrument drift during use.

If at any time during a field investigation, it appears that the environmental conditions could jeopardize the quality of the measurement results, the measurements will be stopped. This will be documented in the field logbook.

3 Field Measurement of Dissolved Oxygen

3.1 General

Dissolved oxygen can be defined as the mass of molecular oxygen contained in a volume of water. The solubility of oxygen in water is dependent on the water temperature, salinity and atmospheric pressure.

- As the temperature of the water decreases, the solubility of oxygen increases.
- As salinity increases, the solubility of oxygen decreases.
- As atmospheric pressure decreases (altitude increases), the solubility of oxygen decreases.

Several methods for measurement of dissolved oxygen in water are available utilizing a variety of technologies. When measuring dissolved oxygen for compliance with the National Pollutant Discharge Elimination System (NPDES) Program, only approved methods will be used. Approved methods can be found in the Code of Federal Regulations (CFR) 40 CFR Part 136.

3.1.1 Clark Cell Probes

Clark cell probes utilize an oxygen permeable membrane that covers an electrolytic cell which consists of a cathode and an anode. The anode acts as a reference electrode. After passing through the permeable membrane, the oxygen is reduced by an applied potential voltage that is referenced to the anode. The reduction current at the cathode is directly proportional to the partial pressure of oxygen in liquid, expressed as %-air saturation. The concentration of oxygen, in mg/l, is calculated based on the %-air saturation reading and the solubility of oxygen in water at the sample temperature.

In general, sample collection using a DO probe requires only lowering the probe into the sample media and recording or logging the results. The probe should be lowered gently to prevent damage to the membrane and gently turned when initially lowered to remove any attached air bubbles. If the instrument requires the use of a stirrer, the stirrer should be turned on before recording any readings. Prior to use, the instrument should be calibrated and any manufacturer specified warm-up period should be observed.

3.1.2 Luminescent Probes

Luminescent dissolved oxygen probes employ a light emitting diode (LED) to provide incident light, which excites the oxygen-sensitive luminescent-dye molecule substrate of the sensor. After dissipation of the excitation energy, longer-wavelength light is emitted (luminescence). The magnitude of steady-state luminescence (intensity) is measured by the sensor and is inversely proportional to the dissolved oxygen concentration.

Sample collection with this type of probe should follow the sample procedures described in the second paragraph of Section 3.1.2 for Clark Cell probes.

3.2 Calibration

Many brands of instruments are commercially available for *in-situ* measurement of dissolved oxygen using Clark cell probes and luminescent probes. The manufacturer's instruction manual should be consulted for specific procedures regarding their calibration, maintenance and use. Calibration of any measurement instrument must be conducted and/or verified prior to each use or on a daily basis, whichever is most appropriate.

In general, calibrations should be conducted at temperatures and pressures as close as possible to those of the sample media for the most accurate measurements. Due to the sensitivity of dissolved oxygen measurements to changes in temperature, the temperature probe or thermistor should be verified using a NIST traceable thermometer prior to each calibration. Most dissolved oxygen meters utilize a one-point calibration which is generally performed using either water-saturated air or air-saturated water. However, some optical DO meters are capable of a two-point calibration at 0% and 100% saturation, refer to Section 3.2.3 for applicability.

3.2.1 Water-Saturated Air Method

When using the water-saturated air method, the probes should be placed in a 100% relative humidity environment open to ambient air temperature and barometric pressure. Allow at least 10-15 minutes for the temperature and dissolved oxygen readings to equilibrate. Ensure that water droplets are removed from the luminescence cap or Clark cell membrane and thermistor before calibration. Refer to Section 3.5 for calibration verification procedure.

3.2.2 Air-Saturated Water Method

When using air-saturated water for calibration, an aeration device such as an aquarium pump with a diffusion stone should be placed in a vessel containing tap water. The water in the vessel should be aerated for a minimum of one hour at a constant temperature. Saturation should be verified by placing the dissolved oxygen probe in the vessel and monitoring the temperature and dissolved oxygen readings for stabilization. Avoid placing the probe in the direct stream of air bubbles. Bubbles can accumulate on the probe surface and cause erroneous readings. Refer to Section 3.5 for calibration verification procedure.

3.2.3 Zero-DO Verification and 2-Point Calibration

It is recommended that a zero-DO verification is conducted periodically or when concentrations are expected to be below 1 mg/l (USGS, 2013*a*). A zero-DO solution can be prepared by dissolving 1 gram of sodium sulfite in 1 liter of deionized water. This should be made fresh weekly or as needed. If the unit is equipped with a wiper, it should be removed before immersing in zero-DO solution. The reading should not exceed a concentration of 0.2 mg/l dissolved oxygen in the zero-DO solution. For Clark cells that exceed this concentration, replace the electrolyte and membrane before repeating the zero-DO verification process. For optical probes that read above 0.2 mg/l in zero-DO solution, replace the sensor cap if it is expired or perform a 2-point calibration if applicable. Some optical DO probes are capable of 2-point calibrations using a zero-DO solution and the air-saturated water method discussed in Section 3.2.2. Refer to the manufacturer's instruction manual for the appropriate 2-point calibration procedure. Ensure that the probe is thoroughly rinsed of zero-DO solution after verification or calibration to avoid measurement interferences caused by residual sodium sulfite.

3.3 Maintenance

Maintenance procedures vary depending on the technology utilized by each instrument and the manufacturer. The manufacturer's instruction manual should be consulted for instrument specific procedures. Following are some general guidelines for maintaining dissolved oxygen meters:

- Inspect probes for damage prior to use.
- For Clark cell probes, membranes and electrolyte solution should be changed prior to each study, when feasible.
- Battery voltages should be checked. For meters that will be deployed unattended, new or fully charged batteries should be used for each study.
- All calibration and maintenance procedures performed should be thoroughly documented.

3.4 Conducting Field Measurement of Dissolved Oxygen

Following are guidelines for conducting field measurements of dissolved oxygen:

- Except as described in specific operating procedures, dissolved oxygen measurements should if possible be conducted *in-situ*.
- When measuring DO at distinct points in the water column, the probe should be allowed to equilibrate at each location prior to recording the measurement.
- In water bodies with a great deal of flow, a weight may be attached to the probe guard or support cable to insure the probe is maintained at the proper depth.
- Insure that the measurement location is representative of conditions within the water body or reach. Avoid measurements directly below turbulent sections or still water unless these conditions represent most of the water body or reach.
- The DO meter should be capable of auto-correcting for specific conductivity/salinity or a separate instrument should be used to measure specific conductivity/salinity so that the final DO measurement(s) can be corrected.

3.5 Operational Verification

A post-calibration and post-operation instrument verification check should be performed using one of the techniques described in Sections 3.2.1 and 3.2.2 or 3.2.3 (for 2-point calibrations) to quantify potential instrument drift during use. A verification check will be performed after a calibration and at the end of all measurements.

It may be appropriate to verify the calibration of a DO meter periodically during the course of a day's measurements when conducting individual measurements. A DO probe may be re-calibrated throughout the day if drift is occurring. The verification DO concentration should be measured and recorded in the field logbook prior to any instrument adjustment. For long-term deployments a post-operation verification should be performed at the end of the deployment.

Verification is done by comparing a post-calibration or post-operation reading at 100% saturation conditions to a DO solubility table value at the ambient air/water temperature and barometric pressure. Post-calibration and post-operation readings should not exceed a maximum of ± 0.2 mg/l from the DO solubility table value. DO solubility tables can be accessed via the U.S. Geological Survey's DOTABLES software (USGS, 2013*b*) which are based on equations from Benson and Krause (1980; 1984).

U.S. Environmental Protection Agency
Region 4, Science and Ecosystem Support Division
Athens, Georgia

OPERATING PROCEDURE

Title: **Field Measurement of Oxidation-Reduction Potential (ORP)**

Effective Date: April 26, 2017

Number: SESDPROC-113-R2

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Revision History

The top row of this table shows the most recent changes to this controlled document. For previous revision history information, archived versions of this document are maintained by the SESD Document Control Coordinator on the SESD local area network (LAN).

History	Effective Date
SESDPROC-113-R2, *Field Measurement of Oxidation-Reduction Potential (ORP)*, replaces SESDPROC-013-R1 **General:** Corrected any typographical, grammatical, and/or editorial errors. **Title Page:** Changed the EIB Chief from Danny France to the Field Services Branch Chief John Deatrick, and the Field Quality Manager from Bobby Lewis to Hunter Johnson. **Section 2.2**: Figure 6 modified for clarity. **Section 3.3**: Use of overtopping cell described consistent with current practice.	April 26, 2017
SESDPROC-113-R1, *Field Measurement of Oxidation-Reduction Potential (ORP)*, replaces SESDPROC-013-R0	January 29, 2013
SESDPROC-113-R0, *Field Measurement of Oxidation-Reduction Potential (ORP)*, Original Issue	August 7, 2009

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1 General Information

1.1 Purpose

This document describes procedures, methods and considerations to be used and observed when conducting field Oxidation-Reduction Potential (ORP) measurements in aqueous environmental media, including groundwater, surface water and certain wastewater. The measurement of soil ORP is a non-standard measurement and procedures should be developed on a project-specific basis.

1.2 Scope/Application

This document describes procedures generic to all ORP measurement methods to be used by Science and Ecosystem Support Division (SESD) field personnel when collecting and handling samples in the field. On the occasion SESD personnel determine that any of the procedures described in this section are inappropriate, inadequate or impractical and that another procedure must be used to obtain an ORP measurement, the variant procedure will be documented in the field logbook, along with a description of the circumstances requiring its use. Mention of trade names or commercial products in this operating procedure does not constitute endorsement or recommendation for use.

1.3 Documentation/Verification

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

1.4 References

Faulkner, S.P., W.H. Patrick, Jr., and R.P. Gambrell. 1989. Field techniques for measuring wetland soil parameters. Soil Sci. Soc. Am. J. 53:883-890.

Megonigal, J.P., W.H. Patrick, Jr., and S.P. Faulkner. 1993. Wetland identification in seasonally flooded forest soils: soil morphology and redox dynamics. Soil Sci. Soc. Am. J. 57:140-149.

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Wikipedia entry. Reduction Potential. http://en.wikipedia.org/wiki/Reduction_potential. Retrieved April 2, 2009.

1.5 General Considerations

1.5.1 Safety

Proper safety precautions must be observed when verifying or calibrating instruments for measurement of Oxidation-Reduction Potential. Refer to the SESD Safety, Health and Environmental Management Program Procedures and Policy Manual (most recent version) and any pertinent site-specific Health and Safety Plans (HASP) for guidelines on safety precautions. These guidelines should be used to complement the judgment of an experienced professional.

Reagents commonly used in the preparation of ORP calibration standards are toxic and require care when handling. When using this procedure, avoid exposure to these materials through the use of protective clothing, eye wear and gloves. Safety precautions when handling and preparing verification solutions should include gloves and eyewear to prevent dermal and eye contact, and a mask to avoid inhaling dust particles when handling dry materials. Vigorous flushing should be used if the reagents or solutions come in contact with skin or eyes. Following is specific information on commonly used solutions. The application of the solutions is described in detail in Section 3.1, Standard Solutions, of this procedure.

- Quinhydrone (CAS# 106-34-3) is a skin and respiratory irritant and is poisonous if ingested. Safety precautions when handling quinhydrone should include gloves to prevent dermal contact and a mask to avoid inhaling dust particles when mixing dry material to prepare calibration standards. Vigorous flushing should be used if concentrated material comes in contact with skin or eyes.

- Zobell's solution is also an irritant and toxic if ingested. The same handling precautions apply when mixing and using Zobell's solution as when using quinhydrone. Zobell's reacts with acid to form harmful byproducts, including hydrocyanide gas.

- Light's solution contains ferro- and ferric-cyanide compounds in sulfuric acid. The components are toxic and burns are possible from contact with this solution.

- Potassium iodide solutions have lower toxicity than most calibration solution options. General ingestion, skin contact, and eye contact precautions apply.

Unused quinhydrone, Zobell's, Light's or other calibration reagents and solutions should be returned to SESD for disposal in accordance with the SESD Safety, Health, and Environmental Management Plan (SHEMP).

1.5.2 Records

Documentation of field activities is done in a bound logbook. All records, including a unique, traceable identifier for the instrument, should be entered according to the procedures outlined in the SESD Operating Procedure for Logbooks (SESDPROC-010, most recent version) and the SESD Operating Procedure for Equipment Inventory and Management, (SESDPROC-108, most recent version).

All field ORP measurements pertinent to the sampling event should be recorded in the field logbook for the event as outlined in the SESD Operating Procedure for Logbooks (SESDPROC-010, most recent version), or managed electronically with appropriate backups as described in SESD Operating Procedure for Control of Records (SESDPROC-002, most recent version).

1.5.3 Shipping

Shipped material shall conform to all U.S. Department of Transportation (DOT) rules of shipment found in Title 49 of the Code of Federal Regulations (49 CFR parts 171 to 179), and/or International Air Transportation Association (IATA) hazardous materials shipping requirements found in the current edition of IATA's Dangerous Goods Regulations.

All shipping documents, such as bills of lading, will be retained by the project leader and stored in a secure place.

2 Background

2.1 General

Oxidation is the process of liberating electrons or gaining oxygen. Examples of oxidation include conversion of elemental iron to rust, elemental sulfur to sulfate, and elemental hydrogen to water (Pankow 1991). Reduction is the process of gaining electrons resulting in the charge on some atomic unit in the species to be reduced. Oxidation-reduction potential (ORP) or redox potential (hereafter, referred to as redox) is a measure of the intensity or activity of an aqueous environment or soil to mediate reactions of important elements in biological systems (e.g., O, N, Mn, Fe, S, and C) and other metallic elements.

Considerable confusion arises on the use of the terms oxidation and reduction as they apply to the media under study. The following introduction reproduced from an online ‘Wikipedia’ article on the topic lucidly explains their relationship in ORP measurement:

> **Reduction potential** (also known as **redox potential**, **oxidation / reduction potential** or **ORP**) is the tendency of a chemical species to acquire electrons and thereby be reduced. Each species has its own intrinsic reduction potential; the more positive the potential, the greater the species' affinity for electrons and tendency to be reduced.
>
> In aqueous solutions, the reduction potential is the tendency of the solution to either gain or lose electrons when it is subject to change by introduction of a new species. A solution with a higher (more positive) reduction potential than the new species will have a tendency to gain electrons from the new species (i.e. to be reduced by oxidizing the new species) and a solution with a lower (more negative) reduction potential will have a tendency to lose electrons to the new species (i.e. to be oxidized by reducing the new species). Just as the transfer of hydrogen ions between chemical species determines the pH of an aqueous solution, the transfer of electrons between chemical species determines the reduction potential of an aqueous solution. Like pH, the reduction potential represents an intensity factor. It does not characterize the capacity of the system for oxidation or reduction, in much the same way that pH does not characterize the buffering capacity.

In short, a numerically positive redox potential or ORP represents an environment conducive to the oxidation of an introduced substance by reduction of the original media.

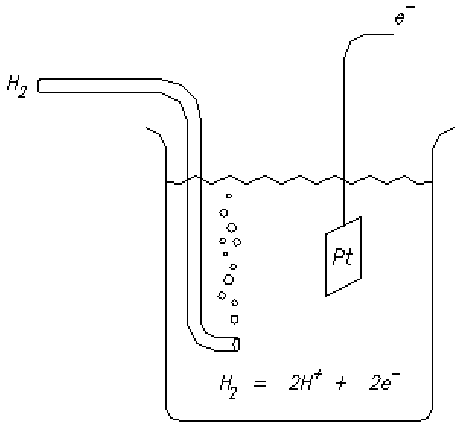
2.2 Instrumentation

ORP measurement systems are a practical implementation of electrochemical cells, which use metal electrodes in a solution to generate an electric current or voltage. If a platinum electrode is immersed in water with hydrogen bubbled into the solution, the H^2 is oxidized as follows:

$$H^2 = 2H^+ + 2e^-$$

In the electrochemical half-cell illustrated below in Fig.1, hydrogen gas oxidizes to hydrogen ions and free electrons, comprising an oxidation-reduction couple. This couple reaches an equilibrium state that maintains the reference potential of the electrode. The electric potential develops on the wire connected to the platinum electrode, but is difficult to measure in practice in the isolated half-cell. However, when used in a complete electrochemical cell, the cell illustrated is used as a reference to measure other half-cells against, and is called a Standard Hydrogen Electrode (SHE).

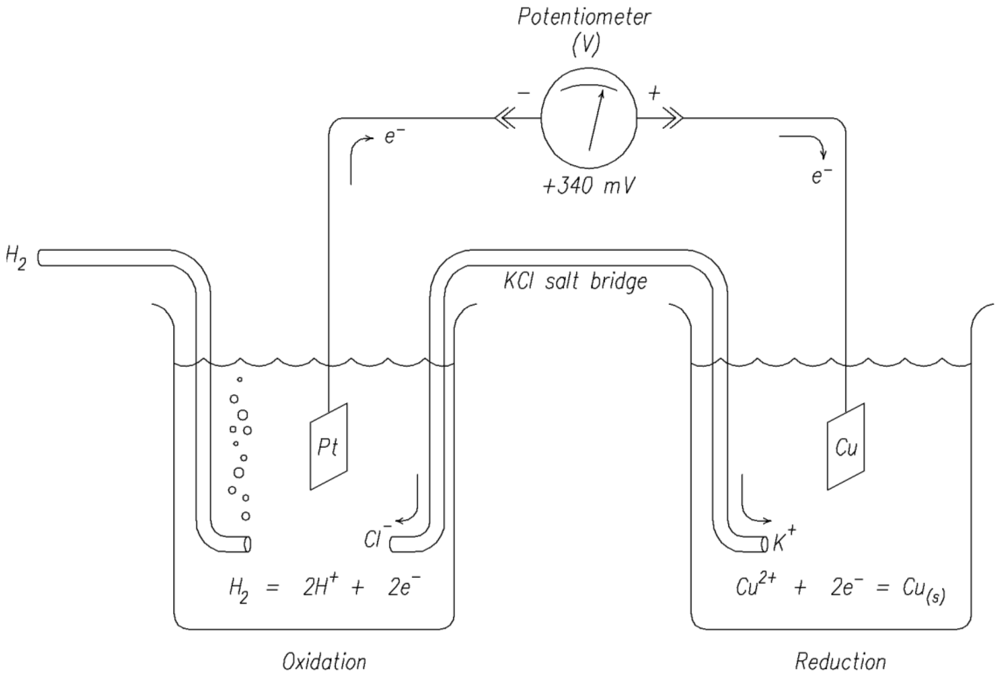
Figure 1



Hydrogen Half–Cell

If, as shown in Figure 2, a SHE is connected with a salt bridge to a second half-cell in which a reduction reaction is taking place, the electric potential between the two cells can be measured. In the case shown, the potential of the right cell will be +0.34 Volts in reference to the standard hydrogen electrode on the left. This would be represented as an Oxidation Reduction Potential (ORP) of +340mV on the hydrogen scale, or simply as Eh = +340mV.

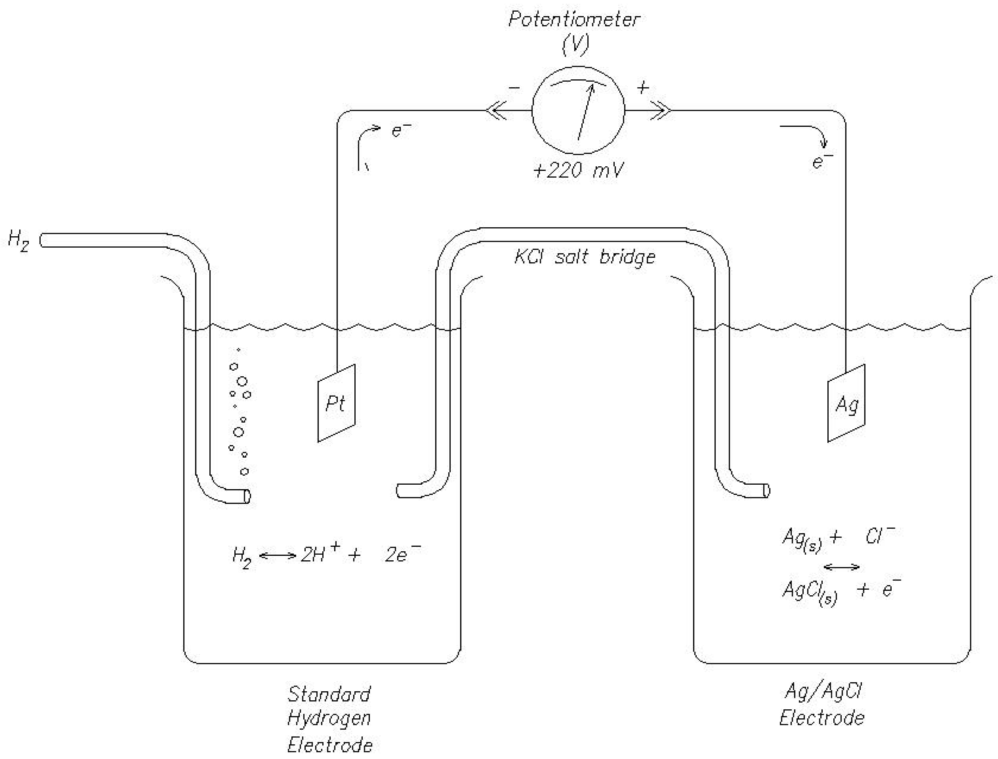
Figure 2



In field practice, the hydrogen electrode is difficult to reproduce. To conduct field measurements, a reference electrode is needed that is simple to maintain and will generate a potential that can be referenced to the standard hydrogen electrode. These requirements are met by the Saturated Calomel Electrode (SCE) and the Silver/Silver Chloride Electrode (SSCE - the SSCE is also commonly identified as an Ag/AgCl electrode). The SCE contains a small amount of elemental mercury, and while useful for certain applications, would rarely be used at SESD. The SSCE or Ag/AgCl electrode is generally used as the reference cell in SESD instrumentation.

In Figure 3 below, a SHE is connected to an Ag/AgCl electrode. In this example of an electrochemical cell, both cells reach an equilibrium potential. At that equilibrium state, the potential of the Ag/AgCl cell is 220mV more positive than the standard hydrogen electrode.

Figure 3



This half-cell potential of the Ag/AgCl electrode in reference to the SHE is used to convert measurements taken with an Ag/AgCl reference back to the hydrogen scale. While the laboratory Ag/AgCl half-cell shown has a potential of +220mV, practical reference cells have varying potentials based on temperature and filling solutions as shown in Table 1 below.

Table 1

Half-cell Potential of Ag/AgCl reference electrode

derived from USGS NFM, Table 6.5.2 (9/2005)

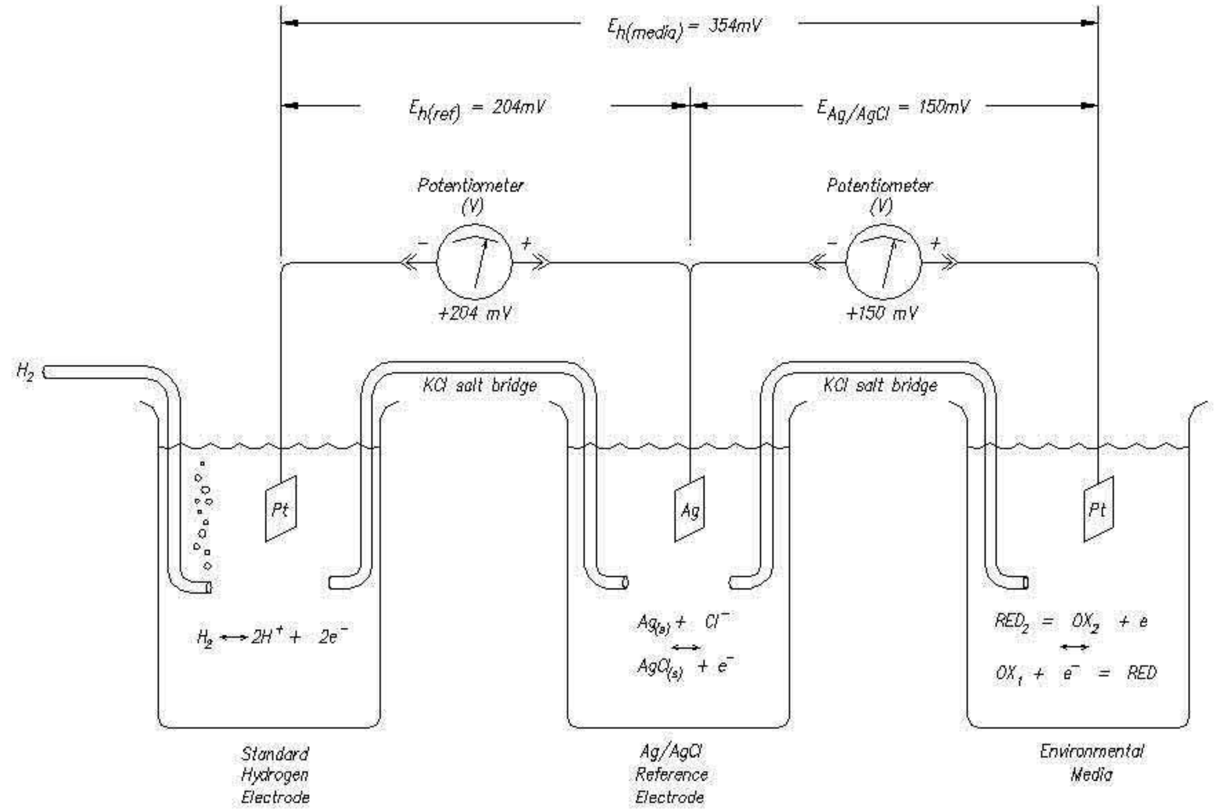
	Molarity of KCl filling solution			
T(°C)	3M	3.3M*	3.5M	Sat/4M
10	220	217	215	214
15	216	214	212	209
20	213	210	208	204
25	209	207	205	199
30	205	203	201	194
35	202	199	197	189
40	198	195	193	184

*interpolated value

Note: YSI sondes and Thermo electrodes typically use 4M KCl filling solutions. Eureka sondes typically use 3.3M KCl filling solutions.

In Figure 4, below, the relationship between a hydrogen electrode, a reference electrode, and a platinum sensing electrode in an arbitrary media is shown. In this case, the ORP of the media in reference to the silver/silver chloride electrode is 150mV. To obtain Eh, the potential of the reference electrode in relation to a hydrogen electrode is added to the potential of the sensing electrode in relation to the reference electrode. In practice, the potential of the reference electrode in relation to a hydrogen electrode is not measured, but obtained from Table 1 above.

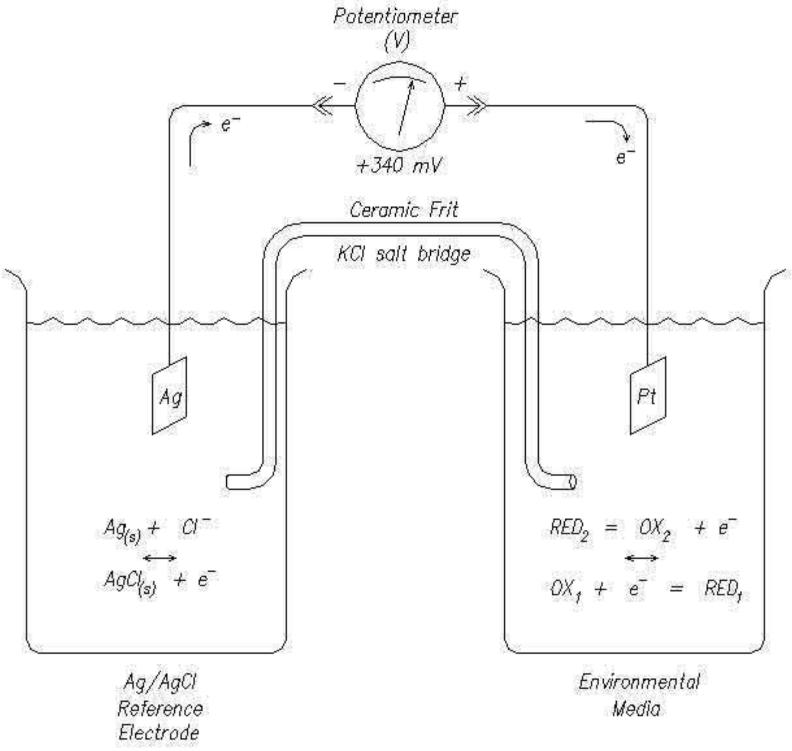
Figure 4



In Figure 5 below, a field instrument is represented as separate electrochemical cells. The

Ag/AgCl reference electrode uses a ceramic frit or other means to provide the essential salt bridge to the environmental media. The platinum sensing electrode is immersed in the environmental media and connected internally in the instrument to measure the potential (voltage) between the two electrodes.

Figure 5



In this illustration, the ORP is measured as 340 mV. This measurement is made in reference to the Ag/AgCl reference electrode and would be reported as such, or as $E_{Ag/AgCl}$ = 340mV.

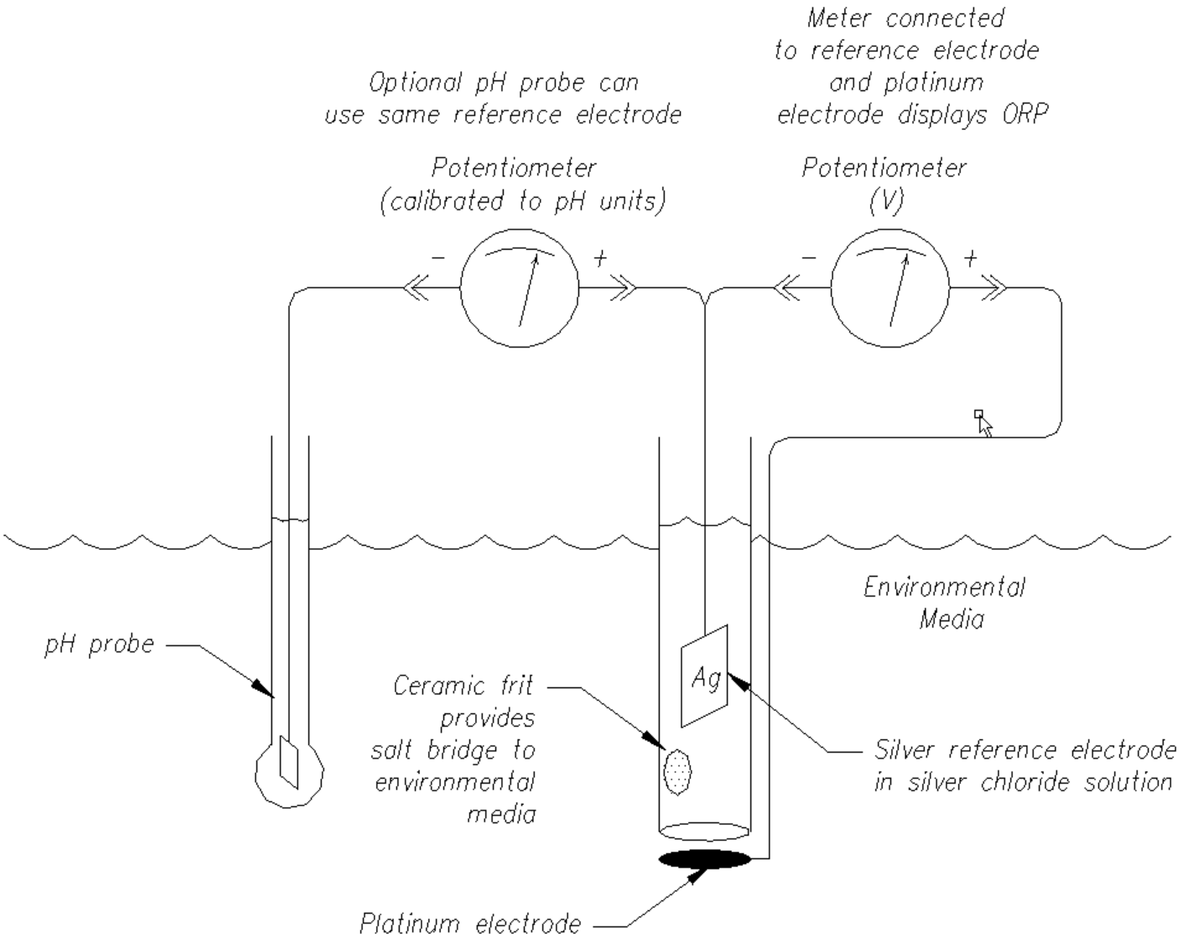
In some cases it will be desirable to report the reading on the hydrogen scale, or Eh. To do so, the potential of the reference electrode against the SHE, obtained from Table 1, is added to $E_{Ag/AgCl}$. For our example:

	340 mv	Measured ORP ($E_{Ag/AgCl}$) of sample
+	204 mV	Eh of Ag/AgCl electrode (ORP of Ag/AgCl electrode referenced to SHE)
	544 mV	Eh of sample

Both the +340 mV field reading and the adjusted +544 mV Eh can properly be referred to as ORP results. It is only through specifying the reference scale that the ambiguity can be eliminated.

In Figure 6, below, the theoretical cells shown above have been configured as a practical field instrument. The salt bridge is commonly provided by a ceramic frit connecting the environmental media to the reference electrode. In multi-parameter sondes, the pH probe commonly uses the same reference electrode as the ORP probe.

Figure 6



Redox Chemistry

In acid-base chemistry, the pH of a system is defined as the negative logarithm of the hydrogen ion activity (simplified in practice to the hydrogen ion concentration):

$$pH = -\log \{H^+\}$$

Similarly, Pankow (1991) described the negative logarithm of the electron activity (pe) as the master variable for describing the equilibrium position for all redox couples in a given system:

$$pe \ / \ -\log \{e^-\}$$

It can be shown (Pankow) that pe is related to Eh by

$$Eh = pe*(2.303*R*T)/F$$

Where:

R = gas constant = 8.314 J K^{-1} mol^{-1}
T = temperature, ^oK
F = Faraday constant = $96.485*10^3$ C mol^{-1}

At 25°C (298°K) this simplifies to

$$E_H = pe * 0.05916$$

And

$$pe = E_H / 0.05916$$

According to Faulkner et al. (1989) redox is a quantitative measure of electron availability and is indicative of the intensity of oxidation or reduction in both chemical and biological systems. When based on a hydrogen scale, redox (E_H) is derived from the Nernst Equation (Stumm and Morgan 1981):

$$E_H = E_H^o + 2.3 \ H \ (R \ H \ T)/nF \ H \log (\vartheta_i \{ox\}^{ni}/\vartheta_j \{red\}^{nj})$$

Where:

E_H^o = potential of reference, mV
R = gas constant = 81.987 cal deg^{-1} $mole^{-1}$
T = temperature, ^oK
n = number of moles of electrons transferred
F = Faraday constant = 23.061 cal/mole-mv
{ox} and {red} = activity of the oxidants and reductants, respectively

2.4 Applications

When interpreted properly, redox combined with other conventional water quality parameters is useful in developing a more complete understanding of water chemistry. Several applications of redox are identified below:

1. Redox could be viewed as an extension of the oxygen scale. In this model, the DO probe spans the aerobic scale and the redox probe extends that scale to measure anaerobic conditions. Inferences to geochemistry and chemical speciation can be made from the oxidative state of the system. Application to metal sequestration, metal-iron, -sulfide, -methane complexation, and the subsequent bioaccumulation potential is possible.
2. Redox can be used to identify anaerobiosis at or near the water column and sediment interface in streams, lakes, and estuaries.
3. Redox may be useful in determination of stream jurisdiction and wetland delineation in that it can indicate conditions of soil saturation.
4. Based on redox, a pe (or EH) vs. pH stability diagram can be developed to aid in nutrient exchange studies including the timing, release, and partitioning of important water and sediment quality pollutants such as nitrogen and phosphorus species. Most importantly, redox can be used to address error associated with chamber-effect during closed chamber measurements of the water-sediment interface. Redox probes placed inside the contact chamber and inserted approximately ten centimeters into the underlying sediment can be used to monitor changes in sediment redox caused by the chamber, and steps can be taken to reduce chamber-effect.
5. Redox may be useful in establishing water and sediment quality standards applicable to wetlands.
6. Redox is used to assess the potential of a groundwater system to support various in situ reactions with contaminants, such as reductive dechlorination of chlorinated solvents.
7. Redox can provide a useful indicator of conditions that might compromise the performance of Clark-type dissolved oxygen (DO) probes. In general, anaerobic conditions occur at a redox range of +150 mV to +300 mV (pH-dependent and adjusted to hydrogen reference electrode). When redox drops below this level, DO measurements as determined with a Clarke-type probe are highly suspect as the semi-permeable membrane does not discriminate between partial O_2 and sulfides. Consequently, the meter may be reading sulfides.

2.5 Limitations

In most environmental media, redox reactions will not reach equilibrium due to low concentrations or multiple redox species. Consequently, redox measurements can generally be considered semi-quantitative in environmental media, unless certain conditions exist.

The USGS in the Interferences and Limitations Section 6.5.3A of their National Field Manual succinctly describe some of the issues encountered in the application of ORP measurements. This section is reproduced here, unedited:

> 6.5.3.A INTERFERENCES AND LIMITATIONS
>
> *Measurements should not be carried out without an awareness of the interferences and limitations inherent in the method.*
>
> - *Organic matter and sulfide may cause contamination of the electrode surface, salt bridge, or internal electrolyte, which can cause drift or erratic performance when reference electrodes are used (American Public Health Association and others, 2001).*
>
> - *Hydrogen sulfide can produce a coating on the platinum electrode that interferes with the measurement if the electrode is left in sulfide-rich water for several hours (Whitfield, 1974; Sato, 1960).*
>
> - *The platinum single and combination redox electrodes may yield unstable readings in solutions containing chromium, uranium, vanadium, or titanium ions and other ions that are stronger reducing agents than hydrogen or platinum (Orion Research Instruction Manual, written commun., 1991).*
>
> - *Do not insert redox electrodes into iron-rich waters directly after the electrode(s) contact ZoBell's. An insoluble blue precipitate coats the electrode surface because of an immediate reaction between ferro- and ferricyanide ions in ZoBell's with ferrous and ferric ions in the sample water, causing erratic readings.*
>
> *Many elements with more than one oxidation state do not exhibit reversible behavior at the platinum electrode surface and some systems will give mixed potentials, depending on the presence of several different couples (Barcelona and others, 1989; Bricker, 1982, p. 59–65; Stumm and Morgan, 1981, p. 490–495; Bricker, 1965, p. 65). Methane, bicarbonate, nitrogen gas, sulfate, and dissolved oxygen generally are not in equilibrium with platinum electrodes (Berner, 1981).*
>
> **TECHNICAL NOTE:**
>
> *Misconceptions regarding the analogy between Eh (pe) and pH as master variables and limitations on the interpretation of Eh measurements are explained in Hostettler (1984), Lindberg and Runnells (1984), Thorstenson (1984), and Berner (1981). To summarize:*

(1) Hydrated electrons do not exist in meaningful concentrations in most aqueous systems—in contrast, pH represents real activities of hydrated protons. Eh may be expressed as pe (the negative logarithm of the electron activity), but conversion to pe offers no advantage when dealing with measured potentials.

(2) Do not assume that redox species coexist in equilibrium. Many situations have been documented in which dissolved oxygen coexists with hydrogen sulfide, methane, and ferrous iron.

- *The practicality of Eh measurements is limited to iron in acidic mine waters and sulfide in waters undergoing sulfate reduction.*

- *Other redox species are not sufficiently electroactive to establish an equilibrium potential at the surface of the conducting electrode.*

(3) A single redox potential cannot be assigned to a disequilibrium system, nor can it be assigned to a water sample without specifying the particular redox species to which it refers. Different redox elements (iron, manganese, sulfur, selenium, arsenic) tend not to reach overall equilibrium in most natural water systems; therefore, a single Eh measurement generally does not represent the system.

3 Methodology

3.1 Standard Solutions

Care should be taken not to contaminate standards and samples and to verify the expiration date of all standards prior to use. All meters should be verified or calibrated according to the manufacturer's procedures.

Standard solutions for calibration and verification should be selected to meet project requirements. SESD generally maintains a stock of Zobell's solution suitable for most projects. The characteristics and use of the common standard solutions are described below.

- Zobell's solution contains potassium ferri- and ferro- cyanide compounds. The solution is available as prepared solutions or premeasured reagents for mixing by the user. Zobell's has moderate toxicity but will react with acid to form harmful byproducts, including hydrocyanide gas. It has a shelf life ranging from several days to several months depending on the manufacturer. Stock and working solutions of Zobell's should be stored in dark bottles due to its light sensitivity.

- Quinhydrone solutions are mixed at the time of use by adding quinhydrone to pH 4 or pH 7 buffers. At 25°C, the E_h of quinhydrone pH 4 and pH 7 verification solutions are 462mV and 285mV respectively. An advantage of quinhydrone solutions is that they offer a span of calibration points that may be appropriate for particular applications. Quinhydrone is a lightly 'poised' solution in that it offers less driving force towards the calibration point: a compromised instrument is more likely to be revealed in a quinhydrone calibration. A quinhydrone calibration/verification solution is created by adding 10g of quinhydrone to 1L of pH 4 or pH 7 buffer solution (ASTM D1498). The solutions are mixed on a magnetic mixing plate for a minimum of 15 minutes to create a saturated solution with undissolved crystals remaining. Quinhydrone solutions are usable for 8 hrs from the time of mixing.

- Light's solution consists of ferrous and ferric ammonium sulphate in sulphuric acid. The solution would rarely be used at SESD due to its high acidity and associated handling difficulty. Spent solutions with a pH<2 would be regulated as a hazardous waste. Light's is a highly poised solution that may allow a marginally functioning electrode to pass calibration.

- A prepared potassium iodide solution is available which has low toxicity and a long shelf life. The solution may stain clothing or surfaces if spilled.

3.2 Verification and Calibration

ORP instruments may be **verified** or **calibrated**, depending on the application. The approach chosen should be selected based on project needs and information presented in Section 2.4., Limitations. Standard laboratory practice in making ORP measurements is to **verify** the accuracy of the instrument prior to use, and this practice should be followed when true quantitative results are required. In a **verification,** the instrument in its direct-reading mode is checked against a standard solution in a pass/no-pass test, and no corrections are applied to subsequent measurements. In most applications, the ORP information is used semi-quantitatively and for these applications, the instruments may be **calibrated** to the standard solutions. In an instrument **calibration**, the instrument probe is placed in the standard solution and the difference between the standard measurement and the known ORP value of the standard is used by the instrument to make adjustments to the subsequent measurements.

In **verification** of an ORP instrument, the instrument is set to absolute mV reading mode or the internal calibration offset is zeroed out. The instrument probe should then be placed in the standard solution and the reading verified to fall within +/-10mV of the predicted reading for the standard. Instruments with single-purpose electrodes are most suitable for this approach. If the instrument fails the verification, standard solution quality should be considered and instrument maintenance performed per the manufacturer's procedures.

In most SESD field practice, the end data use is semi-quantitative. In this case, the instruments can be **calibrated** to standard solutions appropriate for the project using the manufacturer's recommended procedure. One minute after the calibration, the instrument should display a stable reading within +/-10mV of the predicted reading. An instrument failing this test should be recalibrated to determine if the problem is inadequate equilibration time. In the event of continued instrument failure, aging or contamination of the standard solution should be considered. Subsequently the electrode should be serviced according to the manufacturer's procedures. Common service procedures include cleaning the platinum electrode with mild abrasives or acids and refilling or replacing the reference electrode.

Prior to a mobilization, all ORP instruments will be checked for proper operation and verified or calibrated against standard solutions. During the field mobilization, each instrument will be calibrated or verified prior to, and verified after, each day's use or deployment.

Even though it is not necessary to re-calibrate ORP instrument at regular intervals during the day, it may be appropriate to occasionally perform operational checks to determine if site conditions, such as an extreme temperature change or submersion of a filling solution port have impacted the instrument's performance. If an operational check is warranted, the field operator should follow the appropriate verification/calibration steps as described above.

The predicted ORP values of standard solutions will be obtained from the manufacturer of prepared solutions, literature, or appropriate values listed in this procedure. Care is in order, as the predicted ORP value is specific for the type of reference electrode used by the probe (either Ag/AgCl or calomel) and the molarity of the filling solution in the reference electrode. To use the solution with another electrode or filling solution, the expected ORP readings for the solution should be converted to Eh for the probes intended for the solution as per the Reporting section of this procedure. Then a table can be compiled for the electrode in use by subtracting the $E_{h,ref}$ for the electrode and filling solution in use. This will be done at the Field Equipment Center (FEC) for the solutions stocked.

Verification solutions should be managed per the manufacturer's directions regarding storage and handling. After instrument verification or calibration, the solution cannot be returned to the stock solution container, although a separate container of working solution can be maintained.

Spent solutions and working solutions should be returned from the field to the SESD laboratory for proper disposal by the SHEMP, or handled as directed by the SHEMP. Properly handled stock solutions may be returned to the FEC for use at that facility.

3.3 Measurement

ORP measurements should be conducted in a fashion that prevents the addition or loss of any potential oxidants or reductants. Results could be compromised by exposing the sample to air or allowing H_2S to off-gas from anoxic samples. Like dissolved oxygen measurements, ORP measurements should be conducted in situ or by using a flow-through cell evacuated of air (see the SESD Operating Procedure for Field Measurement of Dissolved Oxygen (SESDPROC-106, most recent version). Good results are commonly obtained with the use of an overtopping cell where the environmental media is pumped into the bottom of a narrow cup (generally field fabricated from a sample container) containing the instrument sensors. The sensors are continually flushed with fresh media as the cup is allowed to overflow. Caution should be exercised at very low flow rates where the media in the cup could potentially re-oxygenate.

When using multi-parameter probes for ORP measurements, the general guidelines for probe deployment described in the SESD Operating Procedure for Field Measurement of Dissolved Oxygen (SESDPROC-106, most recent version) and the SESD Operating Procedure for In situ Water Quality Monitoring (SESDPROC-111, most recent version) apply.

ORP probes must be operated and maintained in accordance with the manufacturer's instructions. Reference electrodes in multi-parameter probes may require regular filling or replacement. Single parameter ORP electrodes may require regular filling and operation in an upright position to assure that proper salt bridge flow is maintained. Platinum electrode surfaces are easily contaminated and polishing or cleaning of the electrodes should be performed as recommended by the manufacturer.

Measurements in field logbooks should be recorded to the nearest mV. The type of reference electrode in use and its filling solution should be recorded in at least one logbook as part of the field project records.

ORP is a temperature sensitive measurement, but ORP instruments are not temperature compensated. Consequently, the media temperature should always be recorded at the same time as the ORP is recorded. Likewise, as ORP is often pH dependent, pH should also be recorded at the time of ORP measurement.

3.4 Reporting

In the absence of a specified reference scale, ORP data has no meaning. Therefore, the reference scale used should always be specified in reporting or discussing the ORP data. ORP measurements converted to a hydrogen scale can be reported as “E_h”. Data reported as the direct field measurement without correction might be described as “ORP referenced to Ag/AgCl electrode” or “$E_{Ag/AgCl}$”. The expectations of the data user should be ascertained or the measurements should be reported in both systems.

To apply corrections to obtain E_h from the direct field measurement, the known half-cell potential of the reference electrode is added to the recorded field ORP value:

$$E_{h,sample} = ORP_{sample} + \text{half-cell potential of reference electrode}$$

The following table, reproduced from Section 2.2, presents the half-cell potential of a silver/silver chloride reference electrode at various temperatures and with various molarities of KCl filling solutions.

Table 1

Half-cell Potential of Ag/AgCl reference electrode

derived from USGS NFM, Table 6.5.2 (9/2005)

	Molarity of KCl filling solution			
T(°C)	3M	3.3M*	3.5M	Sat/4M
10	220	217	215	214
15	216	214	212	209
20	213	210	208	204
25	209	207	205	199
30	205	203	201	194
35	202	199	197	189
40	198	195	193	184

*interpolated value

Note: YSI sondes and Thermo electrodes typically use 4M KCl filling solutions. Eureka sondes typically use 3.3M KCl filling solutions

Example:

A multi-parameter probe with a silver/silver chloride reference electrode and 4M KCl filling solution is used to record a stream ORP measurement of 146mV. The stream temperature is recorded as 15°C.

From the above table, the half-cell potential of an Ag/AgCl reference electrode filled with 4M KCl is 209mV at 15°C. Then:

$$E_{h,sample} = ORP_{Ag/AgCl,sample} + \text{half-cell potential of Ag/AgCl reference electrode}$$

$$E_{h,sample} = 146mV + 209mV$$

$$E_{h,sample} = 355mV$$

As noted in Section 3.3, Measurement, ORP measurements are sensitive to temperature, and may be sensitive to pH. As the instruments do not compensate for these parameters, ORP data should always be reported with the temperature and pH of the media at the time of measurement.

Final reporting values of Eh or ORP should be rounded to the nearest 10mV. The following spreadsheet formula can perform the rounding of an interim result located in spreadsheet cell ‘A1’:

=INT(A1/10+0.5)*10

Region 4
U.S. Environmental Protection Agency
Laboratory Services and Applied Science Division
Athens, Georgia

Operating Procedure

Title: Field pH Measurement	ID: LSASDPROC-100-R5
Issuing Authority: LSASD Field Branch Chief	
Review Issue Date: July 23, 2020	Review Due Date: July 23, 2024

Purpose

This document describes procedures, methods and considerations to be used and observed when conducting field pH measurements in aqueous phase environmental media, including groundwater, surface water and certain wastewaters.

Scope/Application

The procedures contained in this document are to be used by field personnel when measuring the pH of aqueous phase environmental media in the field. On the occasion that LSASD field personnel determine that any of the procedures described in this section cannot be used to obtain pH measurements of the media being sampled, and that another method must be used to obtain said measurements, the variant instrument and/or measurement procedure will be documented in the field logbook and subsequent investigation report, along with a description of the circumstances requiring its use. Mention of trade names or commercial products in this operating procedure does not constitute endorsement or recommendation for use.

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1 General Information

1.1 Documentation/Verification

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

1.2 General Precautions

1.2.1 Safety

Proper safety precautions must be observed when conducting field pH measurements. Refer to the LSASD Safety, Health and Environmental Management Program Procedures and Policy Manual (Most Recent Version) and any pertinent site-specific Health and Safety Plans (HASPs) for guidelines on safety precautions. These guidelines, however, should only be used to complement the judgment of an experienced professional. Address chemicals that pose specific toxicity or safety concerns and follow any other relevant requirements, as appropriate.

1.2.2 Procedural Precautions

All field pH measurements pertinent to the sampling event should be recorded in the field logbook for the event. All records, including a unique, traceable identifier for the instrument, such as a property number or serial number, should be entered according to the procedures outlined in the LSASD Operating Procedure for Logbooks (LSASDPROC-010) and the LSASD Operating Procedure for Equipment Inventory and Management, (LSASDPROC-108). Care should be taken not to contaminate standards and samples and verify the expiration date of all standards prior to use. All meters should be calibrated, operated and maintained according to the manufacturer's specifications.

2 Quality Control

All pH meters will be maintained and operated in accordance with the manufacturer's instructions and the LSASD Operating Procedure for Equipment Inventory and Management (LSASDPROC-108). Before a meter is taken to the field, it will be properly calibrated or verified, according to Section 3.2 of this procedure, to ensure it is operating properly. These calibration and verification checks will be documented and maintained in a logbook.

The ambient temperature in the immediate vicinity of the meter should be measured and recorded in the field logbook to ensure the instrument is operated within the manufacturer's specified range of operating temperatures, although this is typically not necessary for ecological studies. For instruments that are deployed for *in-situ* measurements, the temperature of the medium being monitored should be measured and recorded in the logbook prior to deployment. *In-situ monitoring equipment may be utilized in unattended deployments where autonomous logging may preclude temperature measurement prior to deployment. Because in-situ instrumentation generally has a wide range of operating temperatures, the field investigator may utilize professional judgment in determining if the operating environment is suitable for unattended deployment.*

If at any time during a field investigation, it appears that the environmental conditions could jeopardize the quality of the measurement results, the measurements will be stopped. This will be documented in the field logbook.

3 Field pH Measurement Procedures

3.1 General

pH is defined as the negative logarithm of the effective hydrogen-ion concentration. The ion selective pH electrode measures the difference in potentials between the two sides in a glass electrode. The circuit is closed through internal solutions of the electrode and the external solution that is being measured and the pH meter. As the electrode is immersed in the test solution the glass bulb senses the positive charged hydrogen ions as millivolts (mV). The pH meter measures the difference between an internal electrode and a reference electrode. This mV reading is then read by the meter and is displayed in pH units. For routine work, a pH meter accurate and reproducible to within 0.2 Standard Units (S.U.) is suitable. For NPDES compliance monitoring, the pH meter should be accurate and reproducible to within 0.1 S.U. Both meters should have a range of 0 to 14 S.U. and be equipped with a temperature-compensation adjustment. Modern pH meters usually have a protective housing around the glass bulb but are sensitive scientific instruments and should be handled with care. Most pH electrodes last from one to two years, depending on the deployment environment and if proper storage solution was used during periods of inactivity.

3.2 Instrument Calibration

Many brands of instruments are commercially available for the measurement of pH incorporating a wide variety of technologies. The manufacturer's instruction manual should be consulted for specific procedures regarding their calibration, maintenance and use. Calibration of any measurement instrument must be conducted and/or verified prior to each use or on a daily basis, whichever is most appropriate. At a minimum, a two-point calibration should be conducted to ensure the accuracy of the meter. The following are basic guidelines for calibration/verification and are provided as an example (procedure may vary based on the instrument used):

1. Verify the meter's internal temperature sensor (thermistor) against a National Institute of Standards and Technology (NIST) traceable thermometer and note any differences between the thermistor and the NIST-traceable thermometer in the logbook. If the temperatures do not agree within ± 4°C, the unit or probe must be repaired or replaced. Alternatively, if the meter can be used in a manual temperature compensation mode, the NIST-traceable thermometer may be used for temperature readings and the necessary corrections applied. Check and record the temperatures of the standards and the samples.

2. If the pH range of the sample is not known, the pH of the sample to be tested should be estimated either from historical data or by using a four-color pH indicator paper or equivalent. Using this information, calibrate the pH meter with the buffers that bracket the expected pH range. Buffer solutions are commonly pH 4, 7 and 10. It may be possible to configure the pH meter so that it can be standardized with buffers other than those in the default configuration. Note that buffer values are temperature specific (reading true at 25°C) and be sure to input the correct buffer calibration value for the given temperature in step 3 below. Some pH probes are capable of Automatic Temperature Compensation (ATC) and will recognize the correct temperate corrected value of the calibration standard.

3. Immerse the probe in the required buffer solutions and record pre-cal values (pH 7 buffer is typically the first cal point). Then re-immerse the probe to calibrate to the correct pH buffer value, also recording the post-cal value. Rinse the probe with de-ionized water and blot dry or otherwise remove excess rinse water between the different buffer solutions. Record the buffer values and temperatures used to calibrate the meter.

4. Rinse the probe with de-ionized water, blot dry or otherwise remove excess rinse water and immerse it into the appropriate buffer and read as a measurement. If the meter reads within ± 0.2 S.U. of the known value of the buffer (for general applications such as ecological studies) or ± 0.1 S.U. (for regulatory applications such as NPDES or drinking water programs), record the value indicated by the meter. If the meter is outside of the acceptable accuracy range, it should be recalibrated. If it is still outside of the acceptable accuracy range after the second calibration, the electrode and/or meter should be replaced.

5. Once the meter has been properly calibrated and verified (steps 1-4 above), it is ready for use. Rinse the probe with de-ionized water and store it according to manufacturer's recommendations. Certain instruments may require being left on until all measurements are performed and the results are recorded. When collecting measurements from grab samples, certain instrument manufacturers recommend that an intermediate check(s) be performed by periodically checking the meter against a known calibration buffers if used for extended periods (> 4 hrs).

6. Unless the manufacturer indicates that the meter maintains its calibration after being turned off, meters must be re-calibrated if they are turned off during their period of use.

    Note: If multi-parameter sondes are used, calibrate according to the manufacturer's specifications and procedural directions. Calibration procedures for sondes for *in-situ* monitoring may in some cases be different than those for field pH meters using open probes. Those procedures are documented in LSASD's SOP listed as: LSASDPROC-111-R4, In-Situ

Water Quality Monitoring

3.3 Field Measurement Procedures

Measurements in the field may occur under several conditions, requiring various specific procedures. A pH probe should never be placed in an analytical sample to avoid cross-contamination, only sample aliquots should be used as a surrogate for sample pH measurements. Use of the word *sample* below implies that a sample aliquot has been collected.

3.3.1 Grab Sample Measurements

These procedures should be followed when conducting field pH measurements of grab sample:

1. Collect a sample. If the meter's thermistor is to be used for the temperature of record for the measurement activity, the temperature should be read as soon as the reading stabilizes and prior to measuring the pH.

   Note 1a: When the pH meter response is slow, unstable, or non-reproducible, it may be necessary to check the conductivity. If the conductivity is lower than 20 to 30 µmhos/cm, it is permissible to add 1 ml of 1M potassium chloride solution per 100 ml of sample to improve response time for the probe. Recheck the pH and record.

   Note 1b: If the pH measurements are to be used for RCRA regulatory purposes and when the pH approaches the alkaline end ($pH \geq 11.0$) of the scale, the pH measurements should be made by a qualified analyst using laboratory quality equipment to control the sample at 25°C ± 1°C.

2. Immerse the lower part of the probe in the sample. Typically, in the field, the pH probe is not kept away from container bottom or sides during calibration, or during field readings in an overtopping cell, as it is not practical. End of day readings are also performed the same way. Allow ample time for the probe to equilibrate with the sample.

3. While suspending the probe in the sample container, record the pH.

4. Rinse the probe with de-ionized water and replace end cap if applicable. For longer term storage, place probe in the manufacturer's recommended storage solution.

3.3.2 Overtopping Cell Measurements

Often during groundwater sampling, an overtopping cell may be used with purge water constantly flowing through the cell during purging. These procedures should be followed when conducting field pH measurements using an overtopping cell:

1. Immerse the bottom portion of the probe in the open-top container being used for purge water

flow-through. Allow it to equilibrate with the purge water and stabilize until the meter indicates that it is ready for readings. Readings may be recorded at certain timed intervals in the field, prior to collecting the sample for laboratory analysis.

2. When finished at one sampling station during the day and moving to the next, the protective end cap should be placed on the probe until ready for use again.

3.3.3 *In-Situ* Measurements

These procedures should be followed when conducting *in-situ* field pH measurements:

1. Place the probe/sonde into the media to be measured and allow the pH and temperature readings to stabilize. Once the readings have stabilized, record the measurements in the logbook.
2. When deploying meters for extended periods of time, ensure the measurement location is representative of average media conditions.

    Note: If multi-parameter sondes are used for pH measurement, procedures such as for depth profiling of pH, may be different than for pH meters with open probes. Those procedures are documented in LSASD's SOP listed as: LSASDPROC-111-R4, In-Situ Water Quality Monitoring.

3.3.4 Sample Preservation Verification

When verifying the pH for sample preservation in a field sample collected for laboratory analysis, this procedure should be followed:

1. Pour a small amount of sample from bottle over a pH strip to determine if the sample has been preserved to the specified pH range; meters are not needed. Be sure to properly dispose of used pH strips, as contaminant level is likely unknown.

3.4 Operational Check

Even though it is not necessary to re-calibrate pH meters at regular intervals during the day, depending on the instrument, it may be appropriate to occasionally perform operational checks to determine if site conditions, such as an increase in temperature, have impacted the meter's performance. If an operational check is warranted, the following procedure should be followed to ensure that the performance of the meter has not changed.

1. While in use, periodically check the pH by rinsing the probe with de-ionized water, blot dry or

otherwise remove excess rinse water and immerse it into the appropriate buffer solution. If the measured pH differs by ≥ 0.2 S.U. or 0.1 S.U. (depending on the application) from the buffer solution, the meter must be re-calibrated.

A post-operation instrument verification check will be performed using the appropriate buffer(s) at the end of the day or after all measurements have been taken for a particular period of operation. These measurements must be recorded in the field logbook.

References

LSASD Operating Procedure for Equipment Inventory and Management, LSASDPROC-108, Most Recent Version

LSASD Operating Procedure for Logbooks, LSASDPROC-010, Most Recent Version

United States Environmental Protection Agency (US EPA). 2001. Environmental Investigations Standard Operating Procedures and Quality Assurance Manual. Region 4 Science and Ecosystem Support Division (LSASD Athens, GA

USEPA. Safety, Health and Environmental Management Program Procedures and Policy Manual. Region 4 LSASD, Athens, GA, Most Recent Version.

Revision History

The top row of this table shows the most recent changes to this controlled document. For previous revision history information, archived versions of this document are maintained by the LSASD Document Control Coordinator on the LSASD local area network (LAN).

History	Effective Date
LSASDPROC-100-R5, *Field pH Measurement,* replaces SESDPROC-100-R4 **General:** Corrected any typographical, grammatical, and/or editorial errors. Updated document format and naming convention. Replaced SESD and FSB with LSASD and ASB throughout due to Agency Re-alignment. Added language to Section 3.2 to specify that pH readings are temperature dependent and include steps for entering the current temperature when calibrating meters. Included language for documenting pre cal and post calibration readings. Section 3.3- clarified that pH meters should not be placed in samples to prevent contamination. Added Section 3.3.2 for performing pH measurement using overtopping cells. Added language for long term storage of probes to Section 3.3.1.3 Updated References	July 23, 2020
LSASDPROC-100-R4, *Field pH Measurement,* replaces LSASDPROC-100-R3 **General:** Corrected any typographical, grammatical, and/or editorial errors. **Title Page:** Changed the Field Quality Manager from Bobby Lewis to Hunter Johnson. Updated cover page to represent LSASD reorganization. John Deatrick was not listed as the Chief of the Field Services Branch	December 16, 2016
LSASDPROC-100-R3, *Field pH Measurement,* replaces LSASDPROC-100-R2	January 29, 2013
LSASDPROC-100-R2, *Field pH Measurement,* replaces LSASDPROC-100-R1	June 13, 2008
LSASD-100-R1, *Field pH Measurement*, replaces LSASDPROC-100-R0	November 1, 2007
LSASDPROC-100-R0, *Field pH Measurement*, Original Issue	February 05, 2007

Region 4
U.S. Environmental Protection Agency
Laboratory Services and Applied Science Division
Athens, Georgia

OPERATING PROCEDURE

Title: Field Specific Conductance Measurement	ID: LSASDPROC-101-R7
Issuing Authority: LSASD Field Branch Chief	
Effective Date: May 5, 2020	Review Date: May 5, 2023

Purpose

This document describes procedures, methods and considerations to be used and observed when conducting field specific conductance measurements in aqueous phase environmental media, including groundwater, surface water and certain wastewaters.

Scope/Application

The procedures contained in this document are to be used by field investigators when measuring the specific conductance of aqueous phase environmental media in the field. On the occasion that LSASD field investigators determine that any of the procedures described in this section cannot be used to obtain specific conductance measurements of the media being sampled, and that another method must be used to obtain said measurements, the variant instrument and/or measurement procedure will be documented in the field logbook, along with a description of the circumstances requiring its use. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

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1 General Information

1.1 Documentation/Verification

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

1.2 General Precautions

1.2.1 Safety

Proper safety precautions must be observed when conducting field specific conductance measurements. Refer to the LSASD Safety, Health and Environmental Management Program Procedures and Policy Manual and any pertinent site-specific Health and Safety Plans (HASPs) for guidelines on safety precautions. These guidelines, however, should only be used to complement the judgment of an experienced professional. Address chemicals that pose specific toxicity or safety concerns and follow any other relevant requirements, as appropriate.

1.2.2 Procedural Precautions

All field specific conductance measurements pertinent to the sampling event, including a unique, traceable identifier for the instrument, such as a property number or serial number, should be recorded in the field logbook for the event. All records should be entered according to the procedures outlined in the LSASD Operating Procedure for Logbooks (LSASDPROC-010, most recent version).

Care should be taken to not contaminate standards and samples and verify the expiration date of all standards prior to use. All meters should be calibrated, operated and maintained according to the manufacturer’s specifications.

2 Quality Control

All specific conductance meters will be maintained and operated in accordance with the manufacturer's instructions and the LSASD Operating Procedure for Equipment Inventory and Management (LSASDPROC-108, most recent version). Before a meter is taken to the field, it will be properly calibrated or verified, according to Section 3.2 of this procedure, to ensure it is operating properly. These calibration and verification checks will be documented and maintained in a logbook.

The ambient temperature in the immediate vicinity of the meter should be measured and recorded in the field logbook to ensure the instrument is operated within the manufacturer’s specified range of operating temperatures. For instruments that are deployed for in-situ measurements, the temperature of the medium being monitored should be measured and recorded in the logbook prior to deployment. *In-situ monitoring equipment may be utilized in unattended deployments where autonomous logging may preclude* *temperature measurement prior to deployment. Because in-situ instrumentation generally has a wide range of operating temperatures, the field investigator may utilize professional judgment in determining if the operating environment is suitable for unattended deployment.*

If at any time during a field investigation it appears that the environmental conditions could jeopardize the quality of the measurement results, the measurements will be stopped. This will be documented in the field logbook.

3 Field Specific Conductance Measurement Procedures

3.1 General

Specific conductance is a measure of the ability of an aqueous solution to conduct an electric current and is customarily reported in microsiemens per centimeter (µS/cm) or micromhos per centimeter (µmhos/cm) at 25°C. It is important to note that if the specific conductance measurements are for NPDES reporting purposes, the meter and conductivity cell should be verified by comparing against a laboratory meter with a platinum-electrode type conductivity cell.

3.2 Instrument Calibration and Verification

Many brands of instruments are commercially available for the measurement of specific conductance incorporating a wide variety of technologies. The manufacturer's instruction manual should be consulted for specific procedures regarding their calibration, maintenance and use. Calibration of any measurement instrument must be conducted and/or verified prior to each use or on a daily basis, whichever is most appropriate.

Conductivity is affected by temperature; therefore, for instruments that do not automatically compensate for temperature, the user should document temperature first so that appropriate adjustments can be made in accordance with the manufacturer's instructions and/or method. The following are basic guidelines for calibration/verification and are provided as an example:

1. Verify the meter's internal temperature sensor (thermistor) against a National Institute of Standards and Technology (NIST) traceable thermometer and note any differences between the thermistor and the NIST-traceable thermometer in the logbook. If the temperatures do not agree within ± 4°C, the unit must be repaired or replaced. Alternatively, if the meter can be used in a manual temperature compensation mode, the NIST-traceable thermometer may be used for temperature readings and the necessary corrections applied. Check and record the temperatures of the standards and the samples.

2. Rinse the probe with de-ionized water and blot dry before conducting the following calibration and verification checks.

3. Immerse the probe in the first standard solution and calibrate or verify the meter against that solution. Fresh standards should be used for each calibration. After the initial standard, calibrate and/or verify the meter using additional standards, as appropriate. Rinse the probe with de-ionized water and blot dry or otherwise remove excess rinse water between the

different standards. Record the standard values/temperatures used to calibrate or verify the meter.

Note: Some instruments require that calibration standards reflect the anticipated specific conductance of the media being measured.

4. Some meters will auto-recognize standards during calibration. For example, the Thermo Star Series meter will auto-recognize standards 1413 µS/cm, 100 µS/cm and 12.9 mS/cm. If the meter is calibrated in a manner where it does not auto-recognize the standard, and the meter is not accurate to ± 10 % of the standard solution(s) known values, the meter or probe should be repaired or replaced. If this condition can be corrected by adjusting the cell constant of the probe, refer to the instruction manual and make the adjustment. Note: The Thermo Star A325 units primarily used for ground water investigations should be set to Temperature Correction mode nLFn for best results.

5. After calibration is complete, place the probe back into the calibration standard used and record a post-calibration reading. Record a post calibration reading for each standard used. If the meter is not accurate to within ± 10 % of the standard solution(s) known values, it should be recalibrated. If it is still outside of the acceptable accuracy range after the second calibration, the probe and/or meter should be replaced.

6. Once the meter has been properly calibrated and verified (steps 1-5 above), it is ready for use. Rinse the probe with de-ionized water and store it in the manufacturer's recommended storage solution. Certain meters may require that the instrument be left on until all sample measurements are performed and the results are recorded. When collecting measurements from grab samples, certain instrument manufacturers recommend that an intermediate check(s) be performed by periodically checking the meter against the known calibration standards if used for extended periods (> 4 hrs).

3.3 Sample Measurement Procedures

The following procedures should be followed when conducting field specific conductance measurements of grab samples:

1. Collect the sample, check and record its temperature.

2. Correct the instrument's temperature adjustment to the temperature of the sample (if required).

3. Immerse the probe in the sample keeping it away from the sides and bottom of the container. It is important that the center portion of the probe be wetted by the sample.

4. Allow meter to stabilize. Record the results in a logbook.

5. Rinse probe with de-ionized water.

The following procedures should be followed when conducting in-situ field specific conductivity measurements:

1. Place the probe into the media to be measured and allow the specific conductivity and temperature readings to stabilize. Once the readings have stabilized, record the measurements in the logbook.

2. When deploying meters for extended periods of time, ensure the measurement location is representative of average media conditions.

3.4 Operational Checks

Even though it is not necessary to re-calibrate conductivity meters at regular intervals during the day, depending on the instrument, it may be appropriate to occasionally perform operational checks to determine if site conditions, such as an extreme temperature change, have impacted the meter's performance. If an operational check is warranted, the following procedures should be followed to ensure that the performance of the meter has not changed.

Check the conductivity meter with fresh conductivity standard. Rinse the conductivity probe with deionized water, blot dry or otherwise remove excess rinse water and immerse it into the appropriate conductivity standard. If the measured conductivity value is not with ± 10% of the standard, the probe should be re-calibrated. If the probe is still not within ± 10% of the standard, the probe should be repaired or replaced. These measurements must be recorded in the field logbook.

A post-operation instrument verification check should be performed using the appropriate standard(s) at the end of the day or after all measurements have been taken for a particular period of operation. These measurements must be recorded in the field logbook.

References

LSASD Operating Procedure for Equipment Inventory and Management, LSASDPROC-108, Most Recent Version

LSASD Operating Procedure for Logbooks, LSASDPROC-010, Most Recent Version

United States Environmental Protection Agency (US EPA). 2001. Environmental Investigations Standard Operating Procedures and Quality Assurance Manual. Region 4 Laboratory Services & Applied Science Division (LSASD), Athens, GA

US EPA. Safety, Health and Environmental Management Program Procedures and Policy Manual. Region 4 LSASD, Athens, GA, Most Recent Version

Revision History

The top row of this table shows the most recent changes to this controlled document. For previous revision history information, archived versions of this document are maintained by the LSASD Document Control Coordinator on the LSASD local area network (LAN).

History	Effective Date
LSASDPROC-101-R7 *Field Specific Conductance Measurement*, replaces SESDPROC-101-R6 **General:** Corrected any typographical, grammatical, and/or editorial errors. Changed references to Division Name to match current organization **Cover Page:** Changed Names of Division and approving officials to reflect current organization. Section 3.2 added a reference to the appropriate temperature compensation setting for the Thermo Star A325.	May5, 2020
SESDPROC-101-R6, *Field Specific Conductance Measurement*, replaces SESDPROC-101-R5 **General:** Corrected any typographical, grammatical, and/or editorial errors. Throughout the document mention of quality system or SESD quality system was replaced with Field Branches Quality System or FBQS. **Cover Page:** Omitted Hunter Johnson as an author. Updated cover page to represent SESD reorganization. John Deatrick was not listed as the Chief of the Field Services Branch.	July 13, 2016
SESDPROC-101-R5, *Field Specific Conductance Measurement*, replaces SESDPROC-101-R4	August 30, 2012
SESDPROC-101-R4, *Field Specific Conductance Measurement*, replaces SESDPROC-101-R3	January 13, 2012
SESDPROC-101-R3, *Field Specific Conductance Measurement*, replaces SESDPROC-101-R2	August 12, 2011
SESDPROC-101-R2, *Field Specific Conductance Measurement*, replaces SESDPROC-101-R1	June 13, 2008
SESDPROC-101-R1, *Field Specific Conductance Measurement*, replaces SESDPROC-101-R0	November 1, 2007
SESDPROC-101-R0, *Field Specific Conductance Measurement*, Original Issue	February 05, 2007

Region 4
U.S. Environmental Protection Agency
Science and Ecosystem Support Division
Athens, Georgia

Operating Procedure

Title: **Field Temperature Measurement**	ID: **SESDPROC-102-R5**
Issuing Authority: Chief, Field Services Branch	
Effective Date: March 14, 2018	

Purpose

This document describes general and specific procedures, methods and considerations to be used and observed when measuring the temperature of aqueous phase environmental media, including groundwater, surface water and certain wastewaters.

Scope/Application

The procedures contained in this document are to be used by field personnel when measuring the temperature of aqueous phase environmental media in the field. On the occasion that SESD field personnel determine that any of the procedures described in this section cannot be used to obtain temperature measurements of the media being sampled, and that another method or measurement instrument must be used to obtain said measurements, the variant instrument and measurement procedure will be documented in the field log book and subsequent investigation report, along with a description of the circumstances requiring its use.

While this SOP may be informative, it is not intended for and may not be directly applicable to operations in other organizations. Mention of trade names or commercial products in this operating procedure does not constitute endorsement or recommendation for use.

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1.0 Field Temperature Measurement Procedures

1.1 General

Field temperature measurements may be made with a field thermometer, equipment thermistor, or NIST-traceable thermometer. At a minimum, the temperature measurement device should be capable of measuring in 0.1°C increments.

1.2 Instrument Verification

1.2.1 Field thermometers and thermistors

Temperature measurement devices such as field thermometers and equipment thermistors will be verified against a NIST-traceable thermometer prior to use and should agree within ± 4.0°C. Corrections may be applied for measurements up to ± 4.0°C depending on investigation objectives, but the instrument must be repaired or replaced beyond that range.

Due to the stable nature of thermistors on multi-parameter water quality instruments, thermistors will be checked at the beginning and end of a field study, but do not have to be checked for every calibration during the study. In order to track stability and reliability, the thermistors on these units will be checked against a NIST-traceable thermometer on an annual basis, with the electronic record of these checks maintained on the Ecology Section Sharepoint Site.

In order to provide the most stable readings, thermistor checks against the NIST-traceable thermometer should be conducted in a liquid calibration standard at stabilized room temperature as opposed to air during the saturated air calibration of dissolved oxygen.

Enforcement cases would still require temperature verification for every calibration and end check related to the case.

1.2.2 NIST-traceable thermometer

Verification of the NIST-traceable thermometers that are used to verify temperature measuring devices is accomplished by comparing temperature readings from the NIST-traceable thermometer to a thermometer that has an independent certification of accuracy traceable to the National Institute of Standards and Testing. Current certified thermometers are maintained by the SESD Analytical Support Branch and are called reference thermometers.

Each NIST-traceable thermometer is verified by comparing at least annually against a reference thermometer. If corrections need to be applied, they will be noted in the NIST-traceable thermometer. Depending on investigation objectives, project leaders may decide to apply the correction factor as necessary.

1.3 Inspections

All temperature measurement devices should be inspected for leaks, cracks, and/or function prior to each use.

1.4 Sample measurement procedures for thermometers/thermistors

(Make measurements in-situ when possible)

1. Clean the probe end with de-ionized water and immerse into sample.
2. If not measuring in-situ, swirl the instrument in the sample for mixing and equilibration.
3. Allow the instrument to equilibrate with the sample for at least one minute.
4. Suspend the instrument away from the sides and bottom, if not in-situ, to observe the temperature reading.
5. Record the reading in the log book. For most applications, report temperature readings to the nearest 0.5°C or to the nearest 0.1°C depending on need.

   Note: Always clean the thermometer with de-ionized water or a detergent solution, if appropriate, prior to storage and/or use.

1.5 Units

Degrees Celsius (°C) or Degrees Fahrenheit (°F)

***Conversion Formulas**:*

°F = (9/5 °C) + 32 or °C = 5/9 (°F - 32)

1.6 Quality Control

All thermometers should be maintained and operated in accordance with the manufacturer's instructions and the SESD Operating Procedure for Equipment Inventory and Management (SESDPROC-108). Temperature measurement devices such as pH, conductivity and dissolved oxygen (DO) meter thermistors will be verified against a National Institute of Standards and Technology (NIST)-traceable thermometer before each use as described in Section 3.2.

If at any time during a field investigation, it appears that the environmental conditions could jeopardize the quality of the measurement results, the measurements will be stopped. This will be documented in the field logbook.

2 Definitions

None

3 References

SESD Operating Procedure for Equipment Inventory and Management, SESDPROC-108, Most Recent Version

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

United States Environmental Protection Agency (US EPA). Most Recent Version. Environmental Investigations Standard Operating Procedures and Quality Assurance Manual. Region 4 Science and Ecosystem Support Division (SESD), Athens, GA

US EPA. Safety, Health and Environmental Management Program Procedures and Policy Manual. Region 4 SESD, Athens, GA, Most Recent Version

4 Revision History

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

History	Effective Date
SESDPROC-102-R5, *Field Temperature Measurement*, replaces SESDPROC-102-R4 **General:** Corrected any typographical, grammatical, and/or editorial errors. Additionally, the document was edited to reflect new Document Control Processes. **Section 1.2.1:** Verification requirements of thermistors on multi-parameter water quality instruments were modified.	March 14, 2018
SESDPROC-102-R4, *Field Temperature Measurement*, replaces SESDPROC-102-R3	October 23, 2014
SESDPROC-102-R3, *Field Temperature Measurement*, replaces SESDPROC-102-R2	February 4, 2011
SESDPROC-102-R2, *Field Temperature Measurement*, Replaces SESDPROC-102-R1	June 13, 2008
SESDPROC-102-R1, *Field Temperature Measurement*, Replaces SESDPROC-102-R0	November 1, 2007
SESDPROC-102-R0, Field Temperature Measurement, Original Issue	February 05, 2007

Region 4
U.S. Environmental Protection Agency
Science and Ecosystem Support Division
Athens, Georgia

OPERATING PROCEDURE

Title: **Field Turbidity Measurement**

Effective Date: July 27, 2017

Number: SESDPROC-103-R4

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Revision History

The top row of this table shows the most recent changes to this controlled document. For previous revision history information, archived versions of this document are maintained by the SESD Document Control Coordinator on the SESD local area network (LAN).

History	Effective Date
SESDPROC-103-R4, *Field Turbidity Measurement*, replaces SESDPROC-103-R3 **General:** Added to Section 3.6 to include application of various turbidity units and associated methods relative to various applications. **Title Page:** Changed Enforcement and Investigations Branch to the Field Services Branch and changed the Chief from Danny France to John Deatrick. Changed Field Quality Manager from Bobby Lewis to Hunter Johnson. **Section 1.4:** Added new references cited in Section 3.5 **Section 3.2:** Added reference to Section 3.5 **Section 3.3.1:** Added Table 1 outlining reporting requirements. **Section 3.5:** Introduced different turbidity units associated with various methods and stated importance of using EPA approved methods for regulatory purposes. Also added Figure 1, a decision tree to assist project leaders in selecting the appropriate method to satisfy Data Quality Objectives, and Table 2, outlining technologies, associated units, application, and design.	July 27, 2017
SESDPROC-103-R3, *Field Turbidity Measurement*, replaces SESDPROC-103-R2	January 29, 2013
SESDPROC-103-R2, *Field Turbidity Measurement*, replaces SESDPROC-103-R1	June 13, 2008
SESDPROC-103-R1, *Field Turbidity Measurement*, replaces SESDPROC-103-R0	November 1, 2007
SESDPROC-103-R0, Field Turbidity Measurement, Original Issue	February 05, 2007

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1 General Information

1.1 Purpose

This document describes general and specific procedures, methods and considerations to be used and observed when conducting field turbidity measurements in aqueous phase environmental media, including groundwater, surface water and certain wastewaters.

1.2 Scope/Application

The procedures contained in this document are to be used by field personnel when measuring turbidity of various, aqueous phase environmental media in the field. On the occasion that SESD field personnel determine that any of the procedures described in this section cannot be used to obtain turbidity measurements of the media being sampled, and that another method or turbidity measurement instrument must be used to obtain said measurements, the variant instrument and measurement procedure will be documented in the field logbook, along with a description of the circumstances requiring its use. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

1.3 Documentation/Verification

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

1.4 References

APHA (1992). Turbidity: Method 2130B. Standard Methods for the Examination of Water and Wastewater, 18th Edition, pp. 2-11.

ASTM International (2012). D7315-12 Standard test method for determination of turbidity above 1 turbidity unit in static mode: ASTM International, Annual Book of Standards, Water and Environmental Technology, v. 11.01, West Conshohocken, Pennsylvania.

SESD Operating Procedure for Equipment Inventory and Management, SESDPROC-108, Most Recent Version

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

USEPA (1993). Method 180.1: Determination of Turbidity by Nephelometry. Rev. 2.0. Environmental Systems Monitoring Laboratory, Office of Research and Development, Cincinnati, Ohio.

USEPA (2001). Environmental Investigations Standard Operating Procedures and Quality Assurance Manual. Region 4 Science and Ecosystem Support Division (SESD), Athens, GA.

USEPA. Safety, Health and Environmental Management Program Procedures and Policy Manual. Region 4 SESD, Athens, GA, Most Recent Version

USGS (2004). Office of Water Quality Technical Memorandum 2004.03: Revision of NFM Chapter 6, Section 6.7- Turbidity, available online at:
http://water.usgs.gov/admin/memo/QW/qw04.03.html

USGS (2005). National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A6.7, available online at http://pubs.water.usgs.gov/twri9A.

USGS (2012). Turbidity parameter and methods codes, available online at:
https://water.usgs.gov/owq/turbidity/Turbidity_parameter_codes_and_methods_codes_(May2012)%20(2).xlsx

1.5 General Precautions

1.5.1 Safety

Proper safety precautions must be observed when conducting field turbidity measurements. Refer to the SESD Safety, Health and Environmental Management Program (SHEMP) Manual (Most Recent Version) and any pertinent site-specific Health and Safety Plans (HASPs) for guidelines on safety precautions. These guidelines, however, should only be used to complement the judgment of an experienced professional. When using this procedure, minimize exposure to potential health hazards through the use of protective clothing, eye wear and gloves. Address chemicals that pose specific toxicity or safety concerns and follow any other relevant requirements, as appropriate.

1.5.2 Procedural Precautions

All field turbidity measurements pertinent to the sampling event should be recorded in the field logbook for the event. All records should be entered according to the procedures outlined in the SESD Operating Procedure for Logbooks (SESDPROC-010).

2 Quality Control

All turbidity meters and probes shall be maintained and operated in accordance with the manufacturer's instructions and the SESD Operating Procedure for Equipment Inventory and Management (SESDPROC-108). Before a meter or probe is taken to the field, it shall be properly calibrated or verified, according to Sections 3.2 and 3.3 of this procedure, to ensure it is operating properly. These calibration and verification checks shall be documented and maintained in a logbook.

The ambient temperature in the immediate vicinity of the meter should be measured and recorded in the field logbook to insure the instrument is operated within the manufacturer’s specified range of operating temperatures. For instruments that are deployed for in-situ measurements, the temperature of the medium being monitored should be measured and recorded in the logbook prior to deployment. *In-situ monitoring equipment may be utilized in unattended deployments where autonomous logging may preclude temperature measurement prior to deployment. Because in situ instrumentation generally has a wide range of operating temperature, the field investigator may utilize professional judgment in determining if the operating environment is suitable for unattended deployment.*

If at any time during a field investigation, it appears that the environmental conditions could jeopardize the quality of the measurement results, the measurements will be stopped. This will be documented in the field logbook.

3 Field Turbidity Measurement Procedures

3.1 General

Turbidity is caused by suspended and colloidal matter such as clay, silt, organic and inorganic matter and microscopic organisms. Many methods are available for the measurement of turbidity including turbidimeters and optical probes. Turbidity is measured by determining the amount of scatter when a light is passed through a sample.

3.2 Instrument Calibration and Verification

Many brands of instruments are commercially available for the measurement of turbidity incorporating a wide variety of technologies (See Section 3.5 for further discussion). The manufacturer's instruction manual should be consulted for specific procedures regarding their calibration, maintenance and use. Calibration of any measurement instrument must be conducted and/or verified prior to each use or on a daily basis, whichever is most appropriate. Depending on the instrument, the verification and calibration can differ slightly. If the instrument readings do not agree within ± 10 % of the calibration standards, the unit must be recalibrated, repaired or replaced. The following are basic guidelines for calibration/verification of meters and are provided as an example:

3.2.1 Meter Calibration and Verification

HACH 2100Q Turbidimeter:

Portable turbidimeters are calibrated with Formazin Primary Standards. The manufacturer recommends calibration with a primary standard such as StablCal® Stabilized Standards or with formazin standards every three months.

Generally only a calibration verification measurement is required in the field; however, if a calibration is needed, record a post calibration reading for each calibration standard used.

Meter Verification:

1. Push **Verify Cal** to enter the Verify menu.
2. Gently invert the liquid standard several times prior to insertion into meter. Insert the 10.0 NTU (or other defined value) Verification Standard and close the Lid.
3. Push **Read**. The display shows "Stabilizing" and then shows the result and tolerance range.

4. Push **Done** to return to the reading display. Repeat the calibration verification if the verification failed. If a meter is unable to pass verification, then that meter will need to be calibrated.

Meter Calibration:

1. Push the **CALIBRATION** key to enter the Calibration mode. Follow the instructions on the display. **Note:** Gently invert each standard several times before inserting the standard and use a non-abrasive, lint-free paper or cloth to wipe off the standards.

2. Insert the 20 NTU StablCal Standard and close the lid. Push **Read**. The display shows "Stabilizing" and then shows the result. Record the result.

3. Repeat Step 2 with the 100 NTU and 800 NTU StablCal Standard. Record both results.

4. Push **Done** to review the calibration details.

5. Push **Store** to save the results. After a calibration is complete, the meter automatically goes into the Verify Cal mode.

3.2.2 Probe Calibration and Verification

The manufacturer's instruction manual should be consulted for specific procedures regarding probe's calibration, maintenance and use. Their calibration must be conducted and/or verified prior to each use or on a daily basis, whichever is most appropriate. The following are basic guidelines for calibration/verification of probes and are provided as an example:

1. Turn the meter "ON" and allow it to stabilize

2. Immerse the probe in the first standard solution and calibrate the probe against the solution.

3. Rinse the probe with de-ionized water, remove excess rinse water and calibrate the probe using additional standards as appropriate.

4. Record the standard values used to calibrate the meter.

3.3 Sample Measurement Procedures

Depending on the meter, the sample measurement procedure can differ slightly.

3.3.1 Grab Sample Measurement

These procedures should be followed when conducting turbidity measurements of grab samples:

1. Collect a representative sample and pour off enough to fill the cell to the fill line (about 15 mL) and replace the cap on the cell.

2. Gently wipe off excess water and any streaks from surface of sampling vial.

3. Turn instrument on. Place the meter on a flat, sturdy surface. Do not hold the instrument while making measurements.

4. Insert the sample cell in the instrument so the diamond or orientation mark aligns with the raised orientation mark in the front of the cell compartment. Close the lid.

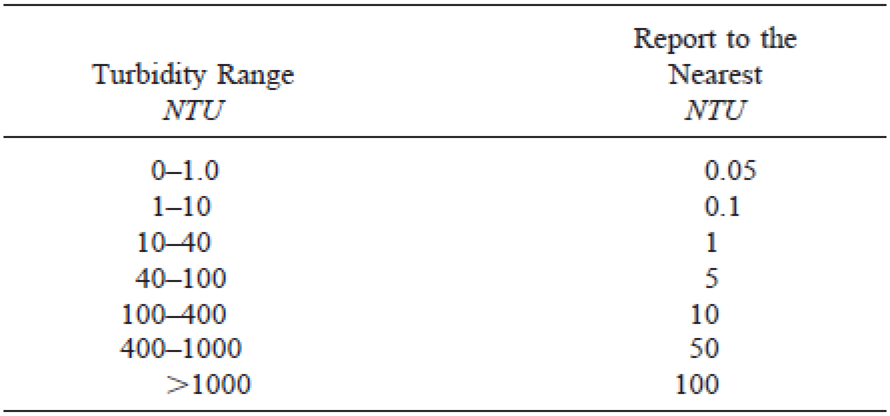
5. If appropriate, select manual or automatic range selection by pressing the range key.

6. If appropriate, select signal averaging mode by pressing the Signal Average key. Use signal average mode if the sample causes a noisy signal (display changes constantly).

7. Press Read. The display will show ---- NTU. Then the turbidity is displayed in NTU. Record the result to the correct range dependent significant digits as required by EPA Method 180.1 Rev. 2.0 (USEPA, 1993) and SM 2130B (APHA, 1992) (Table 1).

8. Rinse the cell with de-ionized water or rinse out with sample water prior to the next reading.

Table 1: Reporting Requirements (APHA, 1992)



Turbidity Range *NTU*	Report to the Nearest *NTU*
0–1.0	0.05
1–10	0.1
10–40	1
40–100	5
100–400	10
400–1000	50
>1000	100

3.3.2 In-Situ Measurement

These procedures should be followed when conducting in-situ turbidity measurements:

1. Place the probe into the media to be measured and allow the turbidity reading to stabilize. Once the reading has stabilized, record the measurement in the logbook.

2. When deploying meters for extended periods of time, ensure the measurement location is representative of average media conditions.

3.4 Operational check

Even though it is not necessary to re-calibrate turbidity meters at regular intervals during the day, depending on the instrument, it may be appropriate to occasionally perform operational checks to determine if site conditions, such as an increase in temperature, have impacted the meter’s performance. If an operational check is warranted, the following procedure should be followed to ensure that the performance of the meter has not changed.

While in use, periodically check the turbidity by rinsing the probe with de-ionized water, blot dry or otherwise remove excess rinse water and immerse it into the appropriate calibration standard. If the measured turbidity differs by ± 10 % (depending on the application) from the calibration standard, the meter must be re-calibrated.

A post-operation instrument verification check will be performed using the appropriate standard(s) at the end of the day or after all measurements have been taken for a particular period of operation. These measurements must be recorded in the field logbook.

3.5 Units and Application

Due to the availability of various technologies for measuring turbidity, the USGS (United States Geological Survey) in collaboration with ASTM International (American Society for Testing and Materials) has determined that data collected using different methods are not directly comparable and should be reported in units reflecting the specific technology used (USGS 2004; ASTM International 2012) (Table 2).

Measurements taken for regulatory purposes (i.e. National Primary Drinking Water Regulations (NPDWR) monitoring, National Pollution Discharge Elimination System (NPDES) reporting) must be in compliance with EPA approved methods. Approved methods for Clean Water Act programs and Safe Drinking Water Act programs can be found in 40 C.F.R. § 136.3 and 40 C.F.R. § 141.74(a)(1), respectively.

Project leaders should consult the decision tree depicted in Figure 1 to determine the appropriate turbidity method that will meet the project specific Data Quality Objectives. For more detailed information on the different methods and their associated units, refer to the USGS National Field Manual for the Collection of Water-Quality Data, Section 6.7 (USGS 2005) and ASTM designation D7315 (ASTM International 2012). A sensor specific spreadsheet detailing methods and associated units can be found on the USGS Field Manual website under turbidity parameter and methods codes (USGS 2012).

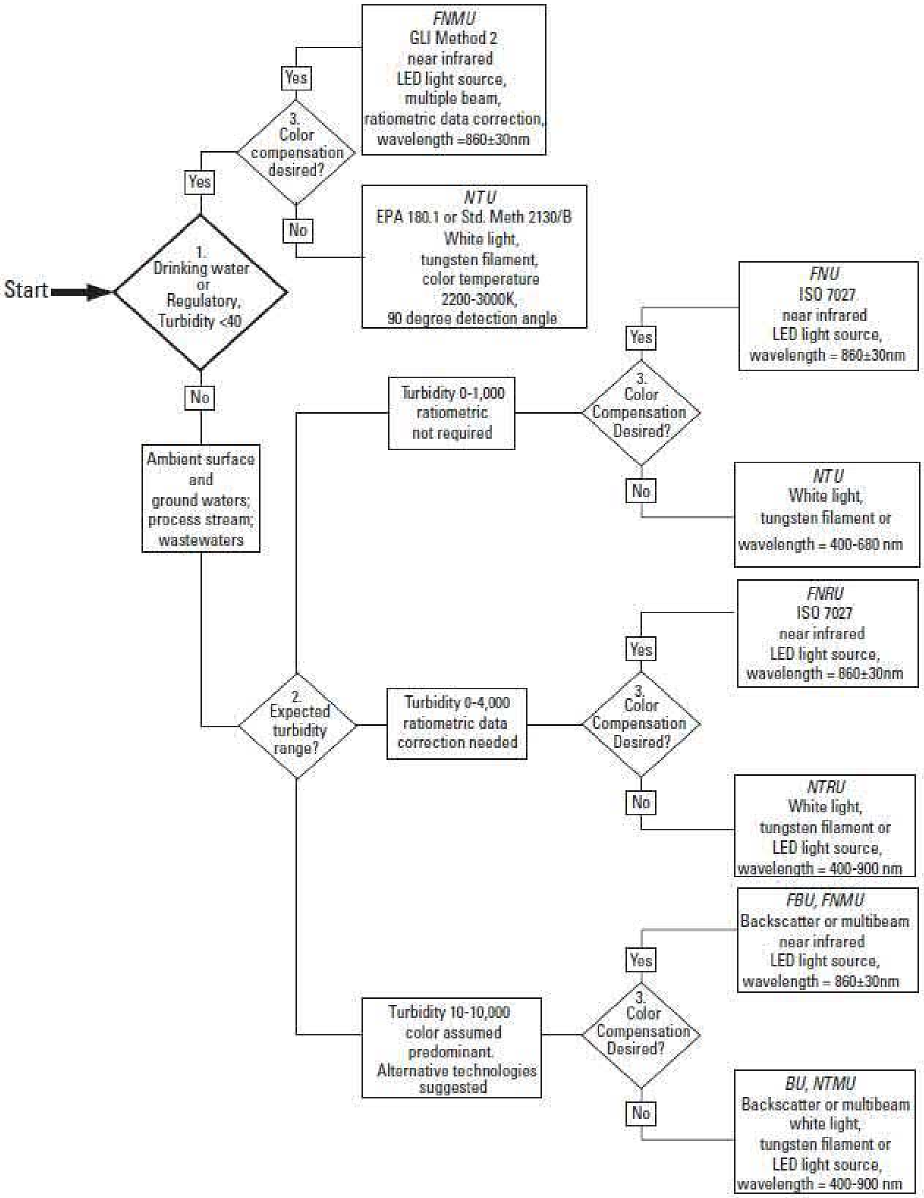


Figure 1: Turbidity Method Decision Tree, adapted from Figure 6.7-2 (USGS 2005)

Table 2: Turbidity Technology, Units, Application, & Design (adapted from ASTM International 2012)

Design and Reporting Unit	Prominent Application	Key Design Features
Nephelometric non-ratio (NTU)	White light turbidimeters. Comply with USEPA Method 180.1 for low level turbidity monitoring.	Detector centered at 90° relative to the incident light beam. Uses a white light spectral source.
Ratio White Light turbidimeters (NTRU)	Complies with ISWTR regulations and Standard Method 2130B. Can be used for both low and high level measurement.	Used a white light spectral source. Primary detector centered at 90°. Other detectors located at other angles. An instrument algorithm uses a combination of detector readings to generate the turbidity reading.
Nephelometric, near-IR turbidimeters, non-ratiometric (FNU)	Complies with ISO 7027. The wavelength is less susceptible to color interferences. Applicable for samples with color and good for low level monitoring.	Detector centered at 90° relative to the incident light beam. Uses a near-IR (780–900 nm) monochromatic light source.
Nephelometric near-IR turbidimeters, ratio metric (FNRU)	Complies with ISO 7027. Applicable for samples with high levels of color and for monitoring to high turbidity levels.	Uses a near-IR monochromatic light source (780–900 nm). Primary detector centered at 90°. Other detectors located at other angles. An instrument algorithm uses a combination of detector readings to generate the turbidity reading.
Surface Scatter Turbidimeters (NTU)	Turbidity is determined through light scatter from or near the surface of a sample.	Detector centered at 90° relative to the incident light beam. Uses a white light spectral source.
Formazin Back Scatter (FBU)	Not applicable for regulatory purposes. Best applied to high turbidity samples. Backscatter is common with but not all only probe technology and is best applied in higher turbidity samples.	Uses a near-IR monochromatic light source in the 780–900 nm range. Detector geometry is between 90° and 180° relative to the incident light beam.
Backscatter Unit (BU)	Not applicable for regulatory purposes. Best applied for samples with high level turbidity.	Uses a white light spectral source (400–680 nm range). Detector geometry is between 90° and 180° relative to the incident light beam.
Formazin attenuation unit (FAU)	May be applicable for some regulatory purposes. This is commonly applied with spectrophotometers. Best applied for samples with high level turbidity.	Detector is geometrically centered at 0° relative to incident beam (attenuation). Wavelength is 780–900 nm.
Light attenuation unit (AU)	Not applicable for some regulatory purposes. This is commonly applied with spectrophotometers.	Detector is geometrically centered at 0° relative to incident beam (attenuation). Wavelength is 400–680 nm.
Nephelometric Turbidity Multibeam Unit (NTMU)	Is applicable to EPA regulatory method GLI Method 2. Applicable to drinking water and wastewater monitoring applications.	Detectors are geometrically centered at 0° and 90°. An instrument algorithm uses a combination of detector readings, which may differ for turbidities varying magnitude.

Region 4 **U.S. Environmental Protection Agency** **Laboratory Services and Applied Science Division** **Athens, Georgia**	
Operating Procedure	
Title: Groundwater Level and Well Depth Measurement	ID: LSASDPROC-105-R4
Issuing Authority: LSASD Field Branch Chief	
Effective Date: May 15, 2020	Review Date: May 15, 2024

Purpose

This document describes general and specific procedures, methods and considerations to be used and observed when determining water levels and depths of wells.

Scope/Application

The procedures contained in this document are to be used by field investigators to measure water levels and depths of wells. On the occasion that LSASD field investigators determine that any of the procedures described in this section are either inappropriate, inadequate or impractical and that another procedure must be used for water level or depth determination, the variant procedure(s) will be documented in the field log book and the subsequent investigation report, along with a description of the circumstances requiring its use

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1 General Information

1.1 Documentation/Verification

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

1.2 General Precautions

1.2.1 Safety

Proper safety precautions must be observed when measuring water levels in wells and determining their depths. Refer to the LSASD Safety, Health and Environmental Management Program Procedures and Policy Manual and any pertinent site-specific Health and Safety Plans (HASPs) for guidelines on safety precautions. These guidelines, however, should only be used to complement the judgment of an experienced professional. Address chemicals that pose specific toxicity or safety concerns and follow any other relevant requirements, as appropriate.

1.2.2 Procedural Precautions

The following precautions should be considered when measuring water levels and depths of wells:

- Special care must be taken to minimize the risk of cross-contamination between wells when conducting water level and depth measurements. This is accomplished primarily by decontaminating the sounders or other measuring devices between wells, according to LSASD Operating Procedure for Field Equipment Cleaning and Decontamination, (LSASDPROC-205) and maintaining the sounders in clean environment while in transit between wells.
- Water levels and well depths measured according to these procedures should be recorded in a bound logbook dedicated to the project as per LSASD Operating Procedure for Logbooks (LSASDPROC-010). Serial numbers, property numbers or other unique identification for the water level indicator or sounder must also be recorded.

2 Quality Control Issues

There are several specific quality control issues pertinent to conducting water level and depth measurements at wells. These are:

- Devices used to measure groundwater levels should be verified annually against a National Institute of Standards and Technology (NIST) traceable measuring tape. These devices should check to within 0.01 feet per 10 feet of length with an allowable error of 0.03 feet in the first 30 feet. Before each use, these devices should be prepared according to the manufacturer's instructions (if appropriate) and checked for obvious damage. All verification and maintenance data should be documented electronically or recorded in a logbook maintained at the Field Equipment Center (FEC) as per the LSASD Operating Procedure for Equipment Inventory and Management (LSASDPROC-108). The functional check and tape length verification should be performed according to the instructions included in LSASDFORM-043, *Well Sounder Function Check and Verification,* which also includes the form for recording the required information.

- These devices should be decontaminated according to the procedures specified in LSASD Operating Procedure for Field Equipment Cleaning and Decontamination (LSASDPROC-205) prior to use at the next well.

3 Water Level and Depth Measurement Procedures

3.1 General

The measurement of the groundwater level in a well is frequently conducted in conjunction with ground water sampling to determine the phreatic water surface. This potentiometric surface measurement can be used to establish ground water direction and gradients. Groundwater level and well depth measurements are needed to determine the volume of water or drawdown in the well casing for proper purging.

All groundwater level and well depth measurements should be made relative to an established reference point on the well casing and should be documented in the field records. This reference point is usually identified by the well installer using a permanent marker for PVC wells, or by notching the top of casing with a chisel for stainless steel wells. By convention, this marking is usually placed on the north side of the top of casing. If no mark is apparent, the person performing the measurements should take both water level and depth measurements from the north side of the top of casing and note this procedure in the field log book.

To be useful for establishing groundwater gradient, the reference point should be tied in with the NAVD88 (North American Vertical Datum of 1988) or a local datum. For an isolated group of wells, it is acceptable to use an arbitrary datum common to all wells in that group.

Water levels should be allowed to equilibrate prior to measurement after removing sealing caps. There are no set guidelines and appropriate equilibration times can range from minutes to hours depending on well recharge, local geology and topography, and project objectives.

3.2 Specific Groundwater Level Measurement Techniques

Measuring the depth to the phreatic ground water surface can be accomplished by the following methods. Method accuracies are noted for each of the specific methods described below.

- Electronic Water Level Indicators – These types of instruments consist of a spool of dual conductor wire, a probe attached to the end and an indicator. When the probe comes in contact with the water, the circuit is closed and a meter light and/or audible buzzer attached to the spool will signal contact. Penlight or 9-volt batteries are normally used as a power source. Measurements should be made and recorded to the nearest 0.01 foot.

- Other Methods – There are other types of water level indicators and recorders available on the market, such as weighted steel tape, chalked tape, sliding float method, air line pressure method and automatic recording methods. These methods are primarily used for closed systems or permanent monitoring wells. Acoustic water level indicators are also available which measure water levels based on the measured return of an emitted acoustical impulse. Accuracies for these methods vary and should be evaluated before selection. Any method not capable of providing measurements to within 0.1 foot should not be used.

3.3 Special Considerations for Water Level Measurements at Sites with Shallow Groundwater Gradient

Groundwater gradients at some sites can be very shallow and if gradient and groundwater flow pattern (gradient direction) determination are part of the project objectives, it is critical that groundwater level measurements obtained from wells are as accurate as possible. Special care should be taken to allow the water level to equilibrate after removing sealing caps and the same sounder should be used for all measurements, if possible. The sounding activity should be coordinated to allow all wells to be sounded within the minimum possible time. This is particularly important in areas with potential tidal influences.

3.4 Total Well Depth Measurement Techniques

The well sounder, weighted tape or electronic water level indicators can be used to determine the total well depth. This is accomplished by lowering the tape or cable until the weighted end is felt resting on the bottom of the well. Because of tape buoyancy and weight effects encountered in deep wells with long water columns, it may be difficult to determine when the tape end is touching the bottom of the well and sediment in the bottom of the well can also make it difficult to determine total depth. Care must be taken in these situations to ensure accurate measurements. The operator may find it easier to allow the weight to touch bottom and then detect the ‘tug’ on the tape while lifting the weight off the well bottom. All total depth measurements must be made and recorded to the nearest 0.1 foot. As a cautionary note, when measuring well depths with the electronic water level indicators, the person performing the measurement must measure and add the length of the probe beneath the circuit closing electrodes to the depth measured to obtain the true depth. This is necessary because the tape distance markings are referenced to the electrodes, rather than the end of the probe. For electronic sounders maintained at the LSASD FEC, the sounder reel will be marked with the appropriate additional length identified as the ‘TD adder’.

3.5 Equipment Available

The following equipment is available for ground water level and total depth measurements:

- Weighted steel measuring tapes
- Electronic water level indicators

4 Establishment of Top of Casing Elevations

To establish groundwater surface elevations, the measured distance from the top of casing to the water surface is subtracted from the well top of casing (TOC) elevation. Obtaining accurate TOC elevations is crucial to developing an accurate groundwater surface elevation map and determination of groundwater flow direction.

The only acceptable means of surveying well TOC elevations is differential leveling conducted to third order standards. Third order differential leveling has allowable error defined by the following formula:

$$Allowable\ Error\ (ft) = 0.05 \times \sqrt{Survey\ loop\ length\ (miles)}$$

This work must be conducted with an auto level as the leveling instrument. Surveying TOC elevations with a total station or survey-grade GPS will not provide the requisite accuracy.

When adding wells to a monitoring network, it is permissible to tie the new well elevations to the known TOC elevations of existing wells in the network. The elevations of several wells in the existing network should be checked to assure that the relative differences in elevation match the recorded elevation data.

Generally, the ground surface elevations at each well should be surveyed at the same time.

5 References

LSASD Operating Procedure for Equipment Inventory and Management, LSASDPROC-108, Most Recent Version

LSASD Operating Procedure for Field Equipment Cleaning and Decontamination, LSASDPROC-205, Most Recent Version

LSASD Operating Procedure for Logbooks, LSASDPROC-010, Most Recent Version

US EPA. Safety, Health and Environmental Management Program Procedures and Policy Manual. Region LSASD, Athens, GA, Most Recent Version

6 Revision History

The top row of this table shows the most recent changes to this controlled document. For previous revision history information, archived versions of this document are maintained by the LSASD Document Control Coordinator on the LSASD local area network (LAN).

History	Effective Date
LSASDPROC-105-R4, *Groundwater Level and Well Depth Measurement*, replaces SESDPROC-105-R3 **General:** Corrected any typographical, grammatical, and/or editorial errors. Updated document template and naming convention. Changed references to SESD to LSASD and FSB to ASB due to organizational name changes from Agency re-alignment. Reformatted and updated naming convention.	May 15, 2020
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Region 4
U.S. Environmental Protection Agency
Science and Ecosystem Support Division
Athens, Georgia

OPERATING PROCEDURE

Title: **Groundwater Sampling**

Effective Date: April 26, 2017

Number: SESDPROC-301-R4

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SESDPROC-301-R1, Groundwater Sampling, replaces SESDPROC-301-R0.	**November 1, 2007**
SESDPROC-301-R0, Groundwater Sampling, Original Issue	**February 05, 2007**

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1 General Information

1.1 Purpose

This document describes general and specific procedures, methods and considerations to be used and observed when collecting groundwater samples for field screening or laboratory analysis.

1.2 Scope/Application

The procedures contained in this document are to be used by field personnel when collecting and handling groundwater samples in the field. On the occasion that SESD field personnel determine that any of the procedures described are either inappropriate, inadequate or impractical and that another procedure must be used to obtain a groundwater sample, the variant procedure will be documented in the field logbook, along with a description of the circumstances requiring its use. Mention of trade names or commercial products in this operating procedure does not constitute endorsement or recommendation for use.

1.3 Documentation/Verification

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

1.4 References

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Puls, Robert W., Don A. Clark, and Bert Bledsoe. 1992. Metals in Ground Water: Sampling Artifacts and Reproducibility. Hazardous Waste and Hazardous Materials 9(2), pp. 149-162.

SESD Guidance Document, Design and Installation of Monitoring Wells, SESDGUID-001, Most Recent Version

SESD Operating Procedure for Control of Records, SESDPROC-002, Most Recent Version

SESD Operating Procedure for Sample and Evidence Management, SESDPROC-005, Most Recent Version

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

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

SESD Operating Procedure for Field pH Measurement, SESDPROC-100, Most Recent Version

SESD Operating Procedure for Field Specific Conductance Measurement, SESDPROC-101, Most Recent Version

SESD Operating Procedure for Field Temperature Measurement, SESDPROC-102, Most Recent Version

SESD Operating Procedure for Field Turbidity Measurement, SESDPROC-103, Most Recent Version

SESD Operating Procedure for Groundwater Level and Well Depth Measurement, SESDPROC-105, Most Recent Version

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

SESD Operating Procedure for Pump Operation, SESDPROC-203, Most Recent Version

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

SESD Operating Procedure for Field Equipment Cleaning and Decontamination at the FEC, SESDPROC-206, Most Recent Version

SESD Operating Procedure for Potable Water Supply Sampling, SESDPROC-305, Most Recent Version

United States Environmental Protection Agency (US EPA). 1975. Handbook for Evaluating Water Bacteriological Laboratories. Office of Research and Development (ORD), Municipal Environmental Research Laboratory, Cincinnati, Ohio.

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US EPA. Analytical Services Branch Laboratory Operations and Quality Assurance Manual. Region 4 SESD, Athens, GA, Most Recent Version

US EPA. Safety, Health and Environmental Management Program Procedures and Policy Manual. Region 4 SESD, Athens, GA, Most Recent Version

Varljen, M., Barcelona, M., Obereiner, J., & Kaminski, D. (2006). Numerical simulations to assess the monitoring zone achieved during low-flow purging and sampling. *Ground Water Monitoring and Remediation*, 26(1), 44-52.

1.5 General Precautions

1.5.1 Safety

Proper safety precautions must be observed when collecting groundwater samples. Refer to the SESD Safety, Health and Environmental Management Program (SHEMP) Procedures and Policy Manual and any pertinent site-specific Health and Safety Plans (HASP) for guidelines on safety precautions. These guidelines, however, should only be used to complement the judgment of an experienced professional. The reader should address chemicals that pose specific toxicity or safety concerns and follow any other relevant requirements, as appropriate.

1.5.2 Procedural Precautions

The following precautions should be considered when collecting groundwater samples.

- Special care must be taken not to contaminate samples. This includes storing samples in a secure location to preclude conditions which could alter the properties of the sample. Samples shall be custody sealed during long-term storage or shipment.
- Always sample from the anticipated cleanest, i.e., least contaminated location, to the most contaminated location. This minimizes the opportunity for cross-contamination to occur during sampling.
- Collected samples must remain in the custody of the sampler or sample custodian until the samples are relinquished to another party.
- If samples are transported by the sampler, they will remain under his/her custody or be secured until they are relinquished.
- Chain-of-custody documents shall be filled out and remain with the samples until custody is relinquished.
- Shipped samples shall conform to all U.S. Department of Transportation (DOT) rules of shipment found in Title 49 of the Code of Federal Regulations (49 CFR parts 171 to 179), and/or International Air Transportation Association (IATA) hazardous materials shipping requirements found in the current edition of IATA's Dangerous Goods Regulations.
- Documentation of field sampling is done legibly, completely, and neatly in a bound logbook.

2 Special Sampling Considerations

2.1 Volatile Organic Compounds (VOC) Analysis

Groundwater samples for VOC analysis must be collected in 40 ml glass vials with Teflon® septa. The vial may be either pre-preserved with concentrated hydrochloric acid or they may be unpreserved. Preserved samples have a two-week holding time, whereas unpreserved samples have only a seven-day holding time. In the majority of cases, the preserved vials are used to take advantage of the extended holding time. In some situations, however, it may be necessary to use the unpreserved vials. For example, if the groundwater has a high amount of dissolved limestone, i.e., is highly calcareous, there will likely be an effervescent reaction between the hydrochloric acid and the water, producing large numbers of fine bubbles and rendering the sample unacceptable. In this case, unpreserved vials should be used and arrangements confirmed with the laboratory to ensure that they can accept the unpreserved vials and meet the shorter sample holding times.

The samples should be collected with as little agitation or disturbance as possible. The vial should be filled so that there is a meniscus at the top of the vial and no bubbles or headspace should be present in the vial after it is capped. After the cap is securely tightened, the vial should be inverted and tapped on the palm or knuckle to check if any undetected bubbles are dislodged. If a bubble or bubbles are present, the vial should be topped off using a minimal amount of sample to re-establish the meniscus. Care should be taken not to flush any preservative out of the vial during topping off. If, after topping off and capping the vial, bubbles are still present, a new vial should be obtained and the sample re-collected. While the 8260 method allows for bubbles up to 6 mm at the time of analysis, dissolved or entrained gases can coalesce during shipment. Collecting VOC vials absent of bubbles is generally feasible and is a reasonable precaution.

2.2 Special Precautions for Trace Contaminant Groundwater Sampling

- Sampling equipment must be constructed of Teflon® or stainless steel materials. Bailers and pumps should be of Teflon® and stainless steel construction throughout.
- New Teflon® tubing should be used at each well, although tubing dedicated to a particular well may be reused, either after decontamination or storage in the well between sampling events. Caution is appropriate in reusing tubing where early sampling events report high concentrations of contaminants.
- A clean pair of new, non-powdered, disposable gloves will be worn each time a different location is sampled and the gloves should be donned immediately prior to sampling. The gloves should not come in contact with the media being sampled and should be changed any time during sample collection when their cleanliness is compromised.
- Sample containers for samples suspected of containing high concentrations of contaminants shall be stored separately.

- Sample collection activities shall proceed progressively from the least suspected contaminated area to the most suspected contaminated area if purging and sampling devices are to be reused. Samples of waste or highly contaminated media must not be placed in the same cooler as environmental (i.e., containing low contaminant levels) or background samples.
- If possible, one member of the field sampling team should take all the notes and photographs, fill out tags, etc., while the other members collect the samples.
- Clean plastic sheeting will be placed on the ground at each sample location to prevent or minimize contaminating sampling equipment by accidental contact with the ground surface.
- Samplers must use new, verified certified-clean disposable or non-disposable equipment cleaned according to procedures contained in SESD Operating Procedure for Field Equipment Cleaning and Decontamination (SESDPROC-205) or SESD Operating Procedure for Field Equipment Cleaning and Decontamination at the FEC (SESDPROC-206) for collection of samples for trace metals or organic compound analyses.

2.3 Sample Handling and Preservation Requirements

1. Groundwater samples will typically be collected from the discharge line of a pump or from a bailer. Efforts should be made to reduce the flow from either the pump discharge line or the bailer during sample collection to minimize sample agitation.

2. During sample collection, make sure that the pump discharge line or the bailer does not contact the sample container.

3. Place the sample into appropriate, labeled containers. Samples collected for VOC, and alkalinity analysis must be collected without headspace. All other sample containers must be filled with an allowance for ullage.

4. All samples requiring preservation must be preserved as soon as practically possible, ideally immediately at the time of sample collection. If pre-preserved VOC vials are used, these will be preserved with concentrated hydrochloric acid by Analytical Services Branch (ASB) personnel prior to departure for the field investigation. For all other chemical preservatives, SESD will use the appropriate chemical preservative generally stored in an individual single-use vial as described in the SESD Operating Procedure for Field Sampling Quality Control (SESDPROC-011). The adequacy of sample preservation will be checked after the addition of the preservative for all samples except for the samples collected for VOC analysis. If additional preservative is needed, it should be added to achieve adequate preservation. Preservation requirements for groundwater samples are found in the USEPA Region 4 Analytical Services Branch Laboratory Operations and Quality Assurance Manual (ASBLOQAM), most recent version.

5. Sample containers should be placed in an ice-filled cooler as soon as possible after filling. Ice in coolers should be in bags with minimal pooled water and the cooler should be periodically checked and replenished to maintain sample storage temperature.

2.4 Quality Control

Equipment blanks should be collected if equipment is field cleaned and re-used on-site or if necessary to document that low-level contaminants were not introduced by pumps, bailers, tubing, or other sampling equipment.

Where appropriate, a background sample upgradient of all known influences or a control sample upgradient of site influences may be indicated. Background and control samples should be collected as close to the sampled area as possible and from the same water-bearing formation as the site samples.

2.5 Records

Information generated or obtained by SESD personnel will be organized and accounted for in accordance with SESD records management procedures found in SESD Operating Procedure for Control of Records, SESDPROC-002. Field notes, recorded in a bound field logbook, will be generated, as well as chain-of-custody documentation in accordance with SESD Operating Procedure for Logbooks, SESDPROC-010 and SESD Procedure for Sample and Evidence Management, SESDPROC-005.

3 Groundwater Purging and Sampling

3.1 Overview of Purging and Sampling Strategies

Purging is the process of removing stagnant water from a well, immediately prior to sampling, causing its replacement by groundwater from the adjacent formation that is representative of aquifer conditions. Sampling is the process of obtaining, containerizing, and preserving (when required) a ground water sample after the purging process is complete. There are several approaches to well purging and sampling that may be appropriate in various circumstances or for various combinations of available equipment. They are briefly summarized below and in *Table 1, Purge and Sample Strategies with Equipment Considerations.*

The M**ultiple-Volume Purge** method involves removing a minimum of three well volumes of water from the top of the water column and then sampling when the well has achieved stability of water quality parameters and adequately low turbidity. This is a traditional method and consistent results are generally obtained with samplers of varying skill. A drawback is that large volumes of purge water may be produced for large diameter or deep wells.

The **Low-Flow** method involves purging the well at a relatively low flow rate that minimizes drawdown, with the pump or tubing inlet located within the screened interval of the well. The well is sampled when water quality parameters are stable, adequately low turbidity is achieved, and the water level has achieved a stable drawdown (an unchanging water level). This method is often faster than Multiple-Volume Purge and generates less purge water. The method requires more skill and judgment on the part of the samplers.

The **Multiple-Volume Purge** method and the **Low-Flow** method can be considered equivalent for conventionally screened and filter-packed wells in that they both sample a flow-weighted average of water entering the well during pumping. However, other variables can result in differences between results with the two methods. In repeat sampling events, the sampling design should not change from one method to the other without appropriate cause. The transition should be noted in the report.

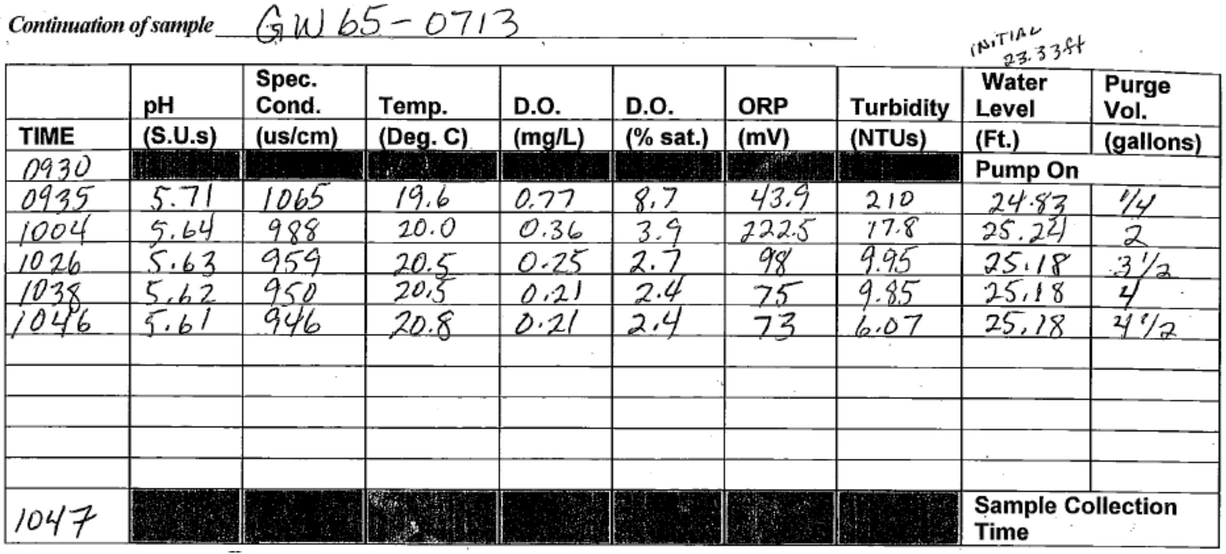
Minimum-Purge and **No-Purge** methods are based on the assumption that water within the screened interval of the well is at equilibrium with the water in the surrounding aquifer. This assumption should be carefully considered in the use of these methods and various cautions are discussed in sections below. The minimal-purge and no-purge methods are most useful for long-term monitoring and are generally inappropriate for the early stages of investigation. In some cases the methods might be used to gather screening-level data from wells that are too large to practically purge or have other sampling complications.

The **Minimum-Purge** and **No-Purge** methods collect water in the vicinity of the device under near-static conditions and are not equivalent to the multiple-volume purge and Low-Flow methods. Stratification of horizontal flow or vertical flow conditions within the well can result in non-intuitive and deceptive results. A comparison study should be conducted before transitioning a sampling program to the minimal-purge or no-purge methods.

3.2 Purging

Wells are purged to eliminate stagnant water residing in the casing and/or screen that has undergone geochemical changes or loss of VOCs. At the conclusion of purging, the desired flow-weighted average of water entering the well under pumping conditions will be available for sampling. Turbidity is often elevated during purging by the disturbance of formation materials at the borehole walls. As many contaminants (metals and many organics) will sorb to the formation particles, a sample including these particles will not represent the dissolved concentrations of the contaminants. Thus, a secondary goal of purging is to reduce the turbidity to the point that the sample will represent the dissolved concentration of contaminants.

In order to determine when a well has been adequately purged, field investigators should monitor, at a minimum, the pH, specific conductance and turbidity of the groundwater removed and the volume of water removed during purging. The measurements should be recorded in a purge table in the field logbook that includes the start time of purging, the parameter measurements at intervals during purging, estimated pumped volumes, depths to water for Low-Flow sampling, and any notes of unusual conditions. A typical purge table used for Low-Flow sampling is reproduced below.



Continuation of sample GW 65-0713

INITIAL 23.33 ft

TIME	pH (S.U.s)	Spec. Cond. (us/cm)	Temp. (Deg. C)	D.O. (mg/L)	D.O. (% sat.)	ORP (mV)	Turbidity (NTUs)	Water Level (Ft.)	Purge Vol. (gallons)
0930								**Pump On**	
0935	5.71	1065	19.6	0.77	8.7	43.9	210	24.83	1/4
1004	5.64	988	20.0	0.36	3.9	222.5	17.8	25.24	2
1026	5.63	959	20.5	0.25	2.7	98	9.95	25.18	3 1/2
1038	5.62	950	20.5	0.21	2.4	75	9.85	25.18	4
1046	5.61	946	20.8	0.21	2.4	73	6.07	25.18	4 1/2
1047								**Sample Collection Time**	

3.3 Parameter Stabilization Criteria

With respect to the ground water chemistry, an adequate purge is achieved when the pH and specific conductance of the ground water have stabilized and the turbidity has either stabilized or is below 10 Nephelometric Turbidity Units (NTUs) (twice the Secondary Drinking Water Standard of 5 NTUs).

Stabilization occurs when, for at least three consecutive measurements, the pH remains constant within 0.1 Standard Unit (SU) and specific conductance varies no more than 5 percent. Other parameters, such as dissolved oxygen (DO) or oxidation-reduction potential (ORP), may also be used as a purge adequacy parameter. Normal stability goals for DO are 0.2 mg/L or 10% change in saturation, whichever is greater. DO and ORP measurements must be conducted using either a flow-through cell or an over-topping cell to minimize oxygenation of the sample during measurement. A reasonable ORP stability goal is a range of 20 mV, although ORP is rarely at equilibrium in environmental media and often will not demonstrate enough stability to be used as a purge stabilization parameter. Determining the frequency of measurements has generally been left to 'Best Professional Judgement'. Care is in order, as measurements recorded at frequent intervals with low flow rates can falsely indicate stability of parameters. Several measurements should be made early in the well purge to establish the direction and magnitude of trends, which can then inform the stability decision. Stability parameters should either be not trending, or approaching an asymptote, when a stability determination is made. As a matter of practice, parameter measurements are generally made at 5-10 minute intervals.

Because the measured groundwater temperature during purging is subject to changes related to surface ambient conditions and pumping rates, its usefulness is subject to question for the purpose of determining parameter stability. As such, it has been removed from SESD's list of parameters used for stability determination. Even though temperature is not used to determine stability, it is still advisable to record the temperature of purge water as it is often used in the interpretation of other parameters.

Information on conducting the stability parameter measurements is available in the SESD Operating Procedures for Field pH Measurement (SESDPROC-100), Field Specific Conductance Measurement (SESDPROC-101), Field Temperature Measurement (SESDPROC-102), Field Turbidity Measurement (SESDPROC-103), Field Measurement of Dissolved Oxygen (SESDPROC-106) and Field Measurement of Oxidation-Reduction Potential (SESDPROC-113).

Table 1, Purge and Sample Strategies with Equipment Considerations

Purging Strategy	Purge Eqpt	Sample Eqpt	Comments
Multi-Volume Purge	------------------------------	------------------------------	Overall Method Comments- Advantages: Consistent results can be achieved with minimal skill level required. Common, simple equipment can be used. Disadvantages: Can result in large volumes of purge water. Can take extended periods of time with large diameter wells or long water columns.
In this traditional method, 3-5 well volumes of water are removed from the top of the water column while verifying the stability of water quality parameters. Following the well purge, the well is sampled from the top of the water column.	Bailer	Bailer	Bailers are rarely used for purging due to the effort required, the difficulty of lowering turbidity adequately, and the possibility of aerating the upper water column.
	Electric Submersible Pump	Bailer	Common multiple-volume setup when depth to water exceeds 25 feet. Abbreviated pump decontamination procedure can be used between wells.
	Electric Submersible Pump	Electric Submersible Pump	Requires full pump decontamination and new tubing at each well. In most cases the pump would be deployed to the screened interval instead to perform Low-Flow sampling.
	Peristaltic Pump	Peristaltic Pump	Common, multi-volume setup when depth to water is less than 25 feet. Special sampling techniques are required for the collection of SVOCs and VOCs.
Low-Flow methods	------------------------------	------------------------------	Overall Method Comments- Advantages: Lower volumes of purge water. May be faster, especially with longer water columns. Disadvantages: Requires greater skill for consistent results. Higher tubing costs than multi-volume method.
The pump or tubing inlet is placed within the screened interval and the well is purged to stable water quality parameters while maintaining stable drawdown of the water level.	Electric Submersible Pump	Electric Submersible Pump	Commonly used when depth to water exceeds 25 feet. Pump is cleaned to sample equipment standards prior to sampling each well and new or dedicated tubing used for each well. Concerns have been raised concerning VOC loss from agitation in the turbine section or from sample heating.
	Peristaltic Pump	Peristaltic Pump	Commonly used where depth to water is less than 25 feet. Special sampling techniques required for the collection of SVOCs and VOCs. Concerns have been raised concerning VOC loss from vacuum created in sample tubing.
	Bladder Pump	Bladder Pump	Least danger of VOC loss as entire sample train is under positive pressure and little sample heating occurs. Difficult to remove large volumes of water in reasonable time. Mild surging effect may keep turbidity elevated in sensitive wells.
Minimum-Purge, No-Purge Methods	------------------------------	------------------------------	Overall Method Comments- Advantages: Very little or no waste water. Well suited to repeat sampling events. Likely faster with lower costs. Disadvantages: Not directly equivalent to other methods. Vertical stratification or vertical flow conditions in the screened interval can result in deceptive or non-intuitive analytical results.
Predicated on the assumption that aquifer flow through the well maintains the water in the screened interval in a state equivalent to that in the aquifer. This assumption should be proven or the data qualified. Sampling is conducted with little or no purge, or by equilibrating a sampler in screened interval.	Pumps, various	Pumps, various	In the minimum-purge method, the internal volume of the sample tubing and pump is calculated. One volume of the pump and tubing is purged to flush the equipment and the well is then sampled.
	na	Passive Diffusion Bags	In most common form, a sealed water-filled polyethylene bag is allowed to equilibrate in the water column. Suitable primarily for VOCs. Generally require 2 week minimum in-situ residence time.
	na	Hydrasleeves	Collect a fixed volume of water from a specific interval. Requires duplicate samplers or redeployment for larger volumes. Sorbtion issues may bias results.
	na	Snap sampler	Deploys a sample container in the sampling interval where it is allowed to equilibrate (commonly for two weeks) before being sealed insitu by the sampler mechanism and retrieved. Limited to specific containers.

3.4 Multiple-Volume Purge

In the traditional Multiple-Volume Purge method, water is removed from the top of the water column, causing water to enter the screen and flush stagnant casing water upward to be subsequently removed. In recognition of the mixing of fresh and stagnant water in the casing section, a minimum of three well volumes is removed, at which time purging can be terminated upon parameter stabilization. Wells can be assumed to be adequately purged when five well volumes have been removed, although further purging may be conducted to meet specific goals, such as further reduction of turbidity.

3.4.1 Purge Volume Determination

Prior to initiating the purge, the amount of water standing in the water column (water inside the well riser and screen) should be determined The diameter of the well is determined and the water level and total depth of the well measured and recorded prior to inserting a pump or tubing into the well. The water level is subtracted from the total depth, providing the length of the water column. Specific methodology for obtaining these measurements is found in SESD Operating Procedure for Groundwater Level and Well Depth Measurement (SESDPROC-105).

Once this information is obtained, the volume of water to be purged can be determined using one of several methods. The well volume can be calculated using the equation:

$$V = 0.041\ d^2h$$

Where:
h = length of water column in feet
d = diameter of well in inches
V = one well volume in gallons

Alternatively, the volume of standing water in the well and the volume of three water columns may be determined using a casing volume per foot factor for the appropriate diameter well, such as *Table 2 Well Casing Diameter Volume Factors*. The water column length is multiplied by the appropriate factor in the Table 2 to determine the single well volume, three well volumes, or five well volumes for the well in question. Other acceptable methods include the use of nomographs or other equations or formulae.

TABLE 2, WELL CASING DIAMETER VOLUME FACTORS

		Reference	Minimum purge	Maximum purge*
		1 Well Volume (gallons/ft)	3 Well Volumes (gallons/ft)	5 Well Volumes (gallons/ft)
Well Casing Diameter (in)	0.5	0.01	0.03	0.05
	0.75	0.02	0.07	0.11
	1	0.04	0.12	0.20
	2	0.16	0.49	0.82
	3	0.37	1.1	1.8
	4	0.65	2.0	3.3
	5	1.0	3.1	5.1
	6	1.5	4.4	7.3
	7	2.0	6.0	10.0
	8	2.6	7.8	13.1
	9	3.3	9.9	16.5
	10	4.1	12.2	20.4
	11	4.9	14.8	24.7
	12	5.9	17.6	29.4
	13	6.9	20.7	34.5
	14	8.0	24.0	40.0
	15	9.2	27.5	45.9
	16	10.4	31.3	52.2
	18	13.2	39.7	66.1
	24	23.5	70.5	118
	36	52.9	159	264
	48	94.0	282	470

*** See text for discussion on terminating purge at five well volumes**

An adequate purge is normally achieved when three to five well volumes have been removed. The field notes should reflect the single well volume calculations or determinations, according to one of the above methods, and a reference to the appropriate multiplication of that volume, i.e., a minimum three well volumes, clearly identified as an initial purge volume goal.

3.4.2 Pumping Conditions

The pump or tubing inlet should be located at the top of the water column. If the pump is placed deep into the water column, the water above the pump may not be removed, and the subsequent samples, particularly if collected with a bailer, may not be representative of the aquifer conditions. If the recovery rate of the well is faster than the pump rate and no observable draw down occurs, the pump should be raised until the intake is as close as possible to the top of the water column for the duration of purging. If the pump rate exceeds the recovery rate of the well, the pump or tubing will have to be lowered to accommodate the drawdown.

3.4.3 Stability of Chemical Parameters

In the multiple-volume purge method, a stability determination may be made after three well volumes have been removed. If the chemical parameters have not stabilized according to the above criteria, additional well volumes (up to a total of five well volumes) should be removed. If the parameters have not stabilized after the removal of five well volumes, it is at the discretion of the project leader whether or not to collect a sample or to continue purging. If, after five well volumes, pH and conductivity have stabilized and the turbidity is still decreasing and approaching an acceptable level, additional purging should be considered to obtain the best sample possible.

3.4.4 Sample Collection

There are several means by which sampling can proceed after adequate volume has been purged and water quality parameters have stabilized. If a submersible pump and tubing are of suitable material and cleanliness for sample collection, sampling can proceed immediately by directly filling bottles from the tubing outlet. Commonly with the multiple-volume purge method, the pump is set up and cleaned in a manner suitable only for purging. In these cases, the pump is stopped and removed from the well and sampling proceeds with a bailer per the procedure described in Section 3.6.3. The pump should have a check valve to prevent water in the pump tubing from discharging back into the well when the pump is stopped. If a peristaltic pump is used, sampling can proceed as described in Section 3.6.1.

3.5 Low-Flow Method

This method involves placing the pump or tubing inlet within the screened interval of the well and purging at a low enough rate to achieve stable drawdown and minimal depression of the water level. The well is sampled without interruption after field parameters are stable and low turbidity is achieved. In general, only water in the screened interval of the well is pumped and the stagnant water in the well casing above the screen is not removed. Wells can generally be sampled in less time with less purge volume than with the multi-volume purge method. More attention is required in the assessment of stability criteria than the multi-volume method.

3.5.1 Nomenclature

A variety of terminology has been used to describe this method by SESD and others, including: ‘low flow’, ‘low-flow/low-volume’, ‘tubing-in-screen method’, ‘low flow/ minimal drawdown’, and ‘micropurge’. The current preferred SESD terminology for this method is ‘Low-Flow’. As the term ‘micropurge’ is sometimes used to refer to minimal-purge methods and has been trademarked by a vendor, the use of ‘micropurge’ to describe the Low-Flow method generally introduces ambiguity and confusion and thus the use of the term is discouraged.

3.5.2 Placement of Pump Tubing or Intake

The inlet of the pump tubing or intake of the submersible pump is placed in the approximate mid-portion of the screened interval of the well. While it is often thought that particular aquifer zones can be targeted by specific pump or intake placement, for conventionally constructed screened and filter-packed monitoring wells the zone monitored is only weakly dependent on the intake placement (Varljen, Barcelona, Obereiner & Kaminski, 2006).

The pump or tubing can be placed by carefully lowering them to the bottom of the well and then withdrawing half of the screen length, plus the length of any sump sections at the bottom of the well. A drawback of this approach is that it may stir up sediment at the well bottom. An alternate approach is to lower the pump or tubing a measured distance to place it at mid-screen without touching the bottom of the well. In the case of pumps, special care should be used in lowering them slowly, especially in the screened interval, to prevent elevating turbidity needlessly by the surging action of the pump.

3.5.3 Conditions of Pumping

Prior to initiation of pumping, a properly decontaminated well sounder should be lowered into the well to measure the water level prior to and during the purging process. Ideally, there should be only a slight and stable drawdown of the water column after pumping begins. In some cases, it will be necessary for the well to drawdown a considerable distance (10 ft or more in extreme cases) to maintain a minimal usable pumping rate for sampling (100-200 ml/min). Excessive pump rates and drawdown can result in increased turbidity, or aeration of the sample if the screen is exposed. Stable drawdown is an essential condition of the Low-Flow method. If the stable drawdown condition cannot be met, then one of the other methods should be employed.

3.5.4 Stability of Chemical Parameters

As with the Multiple-Volume Purging method described, it is important that all chemical parameters be stable prior to sampling. It is common for wells to require the removal of one of more screened-interval volumes (~2 gal for a 10 ft screen in a 2” dia. well) to achieve stability. Although it is possible for wells to achieve stability with lower purge volumes, the sampler should exercise caution in making an early stability determination.

3.5.5 Sample Collection

Low-Flow sampling is implemented using a pump and tubing suitable for sampling. After making the determination of parameter stability with stable drawdown, sampling can proceed immediately. Where submersible or bladder pumps are used, sampling can proceed by directly filling bottles from the tubing outlet. Where peristaltic pumps are used, sampling can proceed per the procedure described in Section 3.6.3.

3.6 Minimum-Purge and No-Purge Sampling

The Minimum-Purge and No-Purge sampling methods are employed when it is necessary to keep purge volumes to an absolute minimum, where it is desirable to reduce long-term monitoring costs, or where large wells or other limitations prevent well purging. The underlying assumption when employing these methods is that the water within the well screen is equilibrated with the groundwater in the associated formation. This assumption should be demonstrated prior to use of these methods or the results suitably qualified. These methods are generally impractical for SESD to implement because of the common lack of hydrogeological information in early investigative phases and the necessity with some methods that the samplers be pre-deployed to allow equilibration.

Vertical flow conditions and stratification of the water column have also been known to result in deceptive and non-intuitive analytical results. The use of these methods in the early phases of investigation can easily result in misinterpretation of site conditions and plume boundaries.

Particular caution is in order in the use of these methods when any of the following conditions exist:

- Low hydraulic conductivity ($K<10^{-5}$ cm/sec)
- Low groundwater surface gradients
- Fractured bedrock
- Wells with long screened intervals
- Wells screened in materials of varying hydraulic conductivities

If it is desired to transition a long-term monitoring program to Minimum-Purge or No-Purge sampling, a pilot study should be conducted where the Minimum-Purge or No-Purge sample results are compared to the conventional methods in use. Multiple samplers may be deployed in the screened interval to help establish appropriate monitoring intervals.

These methods are in common use and for the purposes of the SESD quality system they can be considered standard, but unaccredited, procedures. Several Minimum-Purge or No-Purge procedures that might be employed are shown below. It is not the intention to recommend particular equipment or vendors, and other equipment that can accomplish the same goals may be suitable.

3.6.1 Minimum Purge Sampling

The pump or tubing inlet is deployed in the screened interval. A volume of water equal to the internal pump and tubing volume is pumped to flush the equipment. Sampling then proceeds immediately. While superficially similar to Low-Flow sampling, the results obtained in this method will be sensitive to the vertical pump or tubing inlet placement and are subject to the limitations described above.

3.6.2 Passive Diffusion Bags

The no-purge Passive Diffusion Bag (PDB) typically consists of a sealed low-density polyethylene (LDPE) bag containing deionized water. They are deployed in the screened interval of a well and allowed to equilibrate, commonly for two weeks, prior to retrieval and decanting of the water into sample containers. Many volatile organic compounds will reach equilibrium across the LDPE material, including BTEX compounds and many chlorinated solvents. Compounds showing poor equilibration across LDPE include acetone, MTBE, MIBK, and styrene. PDBs have been constructed of other materials for sampling other analytes, but the vast majority of PDB samplers are of the LDPE material. Various vendors and the Interstate Technology and Regulatory Council (ITRC) can provide additional information on these devices.

3.6.3 HydraSleevesTM

HydraSleeeves^{TM} are no-purge grab sampling devices consisting of a closed-bottom sleeve of low-density polyethylene with a reed valve at the top. They are deployed in a collapsed state to the desired interval and fill themselves through the reed valve when pulled upward through the sampling interval. The following is a summary of their operation:

> Sampler placement – A reusable weight is attached to the bottom of the sampler or the sampler is clipped to a weighted line. The HydraSleeve^{TM} is lowered on the weighted line and placed with the top of the sampler at the bottom of the desired sampling interval. In-situ water pressure keeps the reed valve closed, preventing water from entering the sampler. The well is allowed to return to equilibrium.
>
> Sample collection - The reed valve opens to allow filling when the sampler is moved upward faster than 1 foot per second, either in one continuous upward pull or by cycling the sampler up and down to sample a shorter interval. There is no change in water level and only minimal agitation during collection.
>
> Sample retrieval - When the flexible sleeve is full, the reed valve closes and the sampler can be recovered without entry of extraneous overlying fluids. Samples are removed by puncturing the sleeve with the pointed discharge tube and draining the contents into containers for sampling or field parameter measurements.

Because the HydraSleeve™ is retrieved before equilibration can occur and they are constructed of non-Teflon® materials, there may be issues with sorbtion of contaminants in the use of this sampler.

3.6.4 Snap Samplers

The Snap Sampler is a patented no-purge groundwater sampling device that employs a double-end-opening bottle with “Snap” sealing end caps. The dedicated, device is deployed at the desired position in the screened interval with up to six Snap Samplers and six individual sampling bottles. The device is allowed to equilibrate in the screened interval and retrieved between 3 and 14 days after deployment. Longer deployments are possible to accommodate sampling schedules.

To operate, Snap Samplers are loaded with Snap Sampler bottles and the "Snap" caps are set into an open position. Samplers are deployed downhole with an attachment/trigger line and left to equilibrate downhole. To collect samples, the Snap Sampler bottles seal under the water surface by pulling a mechanical trigger line, or using an electric or pneumatic trigger system. The trigger releases Teflon® "Snap Caps" that seal the double-ended bottles. The end caps are designed to seal the water sample within the bottles with no headspace vapor. After the closed vial is retrieved from the well, the bottles are prepared with standard septa screw caps and labeled for laboratory submittal.

The manufacturer of the Snap Sampler provides considerable additional information on the validation and use of the device.

3.7 Equipment Considerations

Equipment choices are dictated by the purging and sampling method used, the depth to water, the quantity of water to be pumped, and quality considerations. The advantages and disadvantages of various commonly used pumps are discussed in the sections below and summarized in *Table 1, Purge and Sample Strategies with Equipment Considerations.* Additional information on the use of individual pumps is available in SESD Operating Procedure for Pump Operation, SESDPROC-203.

3.7.1 Use of Peristaltic Pumps

Peristaltic pumps are simple, inexpensive, and reliable equipment for purging and sampling where the limit of suction is not exceeded (approximately 25-30 vertical feet from the groundwater surface to the pump). When used for sampling, they should be equipped with new Teflon® tubing for each well. The flexible peristaltic pump-head tubing should also be changed between wells.

Samples for organic analyses cannot be exposed to the flexible peristaltic pump-head tubing, both due to the risk that the tubing would sorb contaminants and the propensity of this tubing to contribute organic compounds to the sample. Samples can be collected without contact with the pump-head tubing by the use of vacuum transfer caps for analyses requiring 1 liter glass containers and the use of the ‘soda-straw’ method for the filling of VOC vials.

The sample containers for the more turbidity-sensitive analyses are filled first, as filling the VOC vials (and to a lesser extent the glass bottles) may disturb the well and increase turbidity. The most appropriate order of sampling with a peristaltic pump is generally to fill poly containers for metals and classical analyses, followed by glass bottles for SVOCs and associated analyses, and finally to fill 40 ml VOC vials.

The following step-by-step procedure assumes that the pump has been set up per SESD Operating Procedure for Pump Operation (SESDPROC-203) and that containers for a typical full suite of analyses will be filled. The procedure is suitable for use with either multi-volume Purge and Low-Flow methods with minor differences in the collection of VOCs:

1. Deploy the lower end of the tubing to the desired point in the well. This would be the top-of-water for the multi-volume purge method or to the mid-screen for the Low-Flow method. Connect the well tubing to the flexible pump-head tubing and connect a short piece of tubing from the pump-head tubing to a measuring bucket.

2. Turn on the pump and establish a suitable pumping rate. For the multi-volume purge method, the rate will generally be a relatively fast rate that the well will sustain without elevating turbidity. For the low-flow method the pump rate is established at a slower rate to maintain a minimal and stable drawdown level.

3. Proceed with the measurement of water quality parameters and adjust the pump rate as needed to achieve low turbidity and stable drawdown.

4. When the well purge has been determined to be sufficient, fill containers for metals and classical analyses directly from the pump outlet. There is no need to interrupt pumping. The tubing should be held at the opening of the container and should not touch the container during filling. Protect caps from dust and debris during filling.

5. After filling the containers for metals and classical analyses stop the pump. Make sure that the tubing leading into the well is secured against movement during the following operations.

6. Create a crimp in the well tubing approximately one foot from the pump and grasp the crimped tubing in one hand. It is generally most effective to create a double ‘Z’ crimp.

7. Cut the sample tubing between the crimp and the pump. The tightly-held crimped tubing should keep water from running back into the well. In lieu of

cutting the tubing, the well tubing can be disconnected from the pump and a short piece of tubing connected in its place.

8. Insert both free ends of the tubing into the ferrule-nut fittings of a pre-cleaned Teflon® transfer cap assembly and tighten the nuts. Attach the transfer cap assembly to the first glass container for semi-volatile analysis and securely tighten the threaded ring.

9. Turn the pump on. Very slowly release the ‘Z’ crimp in the sample tubing. As vacuum builds up in the sample container, water should begin to move up the sample tubing instead of back into the well. If after several minutes water has not begun moving up the tubing, check the tightness of fittings and the attachment of the cap to the bottle. Allowing water to rush back down the tubing from the ‘Z’ crimp can surge the well and elevate turbidity.

10. Fill the container to about halfway between the shoulder and the neck. Crimp the well tubing. Move the transfer cap to any additional bottles and repeat the filling process.

11. When finished filling bottles with the transfer cap, again crimp the tubing. Remove the well tubing from the transfer cap and reattach it to the pump. Slowly run the pump and release the crimp until water is approaching the flexible peristaltic tubing.

12. Make a kink or otherwise mark the tubing at the top of the casing in case the tubing needs to be reinserted for additional sample volume. Slowly remove the tubing from the well and coil it in one hand in loose coils. With the top end of the tubing blocked, water is retained in the tubing as it is withdrawn, much as in a capped soda straw, hence the name for this method.

13. Remove the top from a 40 ml VOC vial and position the end of the sample tubing near the top of the vial. Reverse the pump direction and turn the speed knob to its slowest position. Turn on the pump and slowly increase speed until water slowly fills the vial. Fill the vial with a slow laminar flow that does not agitate the water in the vial or entrain bubbles. Continue to fill the vial until a convex meniscus forms on the top of the vial and turn off the pump.

14. Carefully screw the septum-lid to the vial and fasten firmly. Invert the vial and tap on your knuckles to check for bubbles. Carefully add additional volume to the vial if necessary. Small bubbles are undesirable but may be unavoidable with some media, especially when using pre-preserved vials.

15. Repeat the filling process for additional vials. Avoid partially filling vials as the available water in the tubing is used. If more volume is required than that contained in the tubing, purge the remaining water from the tubing and reinsert

the tubing in the well to the level marked previously. Run the pump to refill the tubing. If performing Low-Flow sampling, run additional volume through the pump to purge any water that may have been collected from the stagnant water column.

16. Fill additional vials as needed. Be sure that any water that has contacted the flexible peristaltic tubing is not pumped into a vial.

3.7.2 Use of Submersible Centrifugal Pumps

Submersible centrifugal pumps are used in wells of 2” diameter and larger. They are especially useful where large volumes of water are to be removed or when the groundwater surface is a large distance below ground surface. Commonly used pumps are the Grundfos® Redi-Flo2, the Geotech GeoSub, and the various ‘Monsoon’ style pumps. Other pumps are acceptable if constructed of suitable materials.

When used with the Multiple-Volume Purge method, the pump is generally used only to purge, with sampling performed with a bailer. In this use, the pump can be used with polyethylene or other tubing or hose that will not contribute contaminants to the well. The pump and tubing is decontaminated between wells per the relevant provisions of SESD Operating Procedure for Field Equipment Cleaning and Decontamination (SESDPROC-205). When used in this application the pump should be equipped with a check valve to prevent water in the discharge tubing or hose from running back down into the well.

When used for Low-Flow purging and sampling the pump must be constructed of stainless steel and Teflon®. Pump cleaning at each well follows the more stringent procedures described in SESD Operating Procedure for Field Equipment Cleaning and Decontamination SESDPROC-205) for this application. The sample tubing should be either new Teflon® tubing, or tubing dedicated to each well. Dedicated tubing would ideally be cleaned between uses, but tubing stored in the well casing between uses is acceptable, although caution should be exercised where very high concentrations of contaminants have been sampled in a well.

3.7.3 Use of Bailers

Bailers are a common means of sampling when the Multiple-Volume Purge method is used. They are occasionally used for purging when other equipment is not available or has failed. As bailers surge the well on each withdrawal, it is very difficult to lower turbidity adequately during a well purge, and when used for sampling they can elevate turbidity in a well before all sample volume is collected. If not lowered carefully into the top of the water column, the agitation may strip volatile compounds. Due to the difficulties and limitations inherent in their use, other sampling or purging means should generally be given preference.

Bailers should be closed-top Teflon® bailers with Teflon® coated stainless steel leaders used with new nylon haul rope. They are lowered gently into the top of the water column, allowed to fill, and removed slowly. It is critical that bailers be slowly and gently immersed into the top of the water column, particularly during final stages of purging and during sampling, to minimize turbidity and loss of volatile organic constituents.

If the well has previously been purged with a pump, there is likely stagnant water at the top of the well that was above the pump or tubing inlet. Several bailers of water should be retrieved and discarded to assure the upper stagnant water has been removed.

When sampling, containers are filled directly by pouring from the outlet at the top of the bailer. Containers for metals analysis should be filled first in case the bailing process increases well turbidity. VOC vials should be filled carefully and slowly with a laminar flow to reduce agitation and the stripping of VOCs.

3.7.4 Use of Bladder Pumps

Bladder pumps use a source of compressed gas to compress and release a bladder straddled by check valves within the pump body. As the bladder is compressed, water is expelled out the upper check valve to the surface. When gas pressure is released, the bladder refills as well water enters the lower pump inlet. A control unit is used to control the pressure and timing of the bladder inflation gas flow.

Bladder pumps are capable of pumping from moderate depths to water, but are not capable of high flow rates. As they operate cyclically, the well is surged slightly on each cycle and it may be difficult to lower turbidity in sensitive or poorly developed wells. As the entire sample train is under positive pressure and the pumps develop little heat, they are ideal for sampling VOCs.

Prior to sampling and between each well the pumps are cleaned internally and externally per the provisions of SESD Operating Procedure for Field Decontamination (SESDPROC-205) and a new Teflon® bladder installed. New (or dedicated) Teflon® sample tubing is used at each well, although polyethylene tubing can be used for the compressed gas drive line and cleaned between each well.

3.7.5 Use of Inertial Pumps

Inertial pumps consist of a check valve which is affixed to the lower end of semi-rigid tubing. The tubing and valve are cycled up and down, allowing water to alternately be drawn into the check valve inlet and then pulled up towards the surface. Two commonly used inertial pumps are the Waterrra® pump for wells 1arger than 1” and the Geoprobe® Tubing Check Valve for small diameter wells. The primary use of these pumps is in well development where their near-immunity to silt is an advantage. Inertial pumps should not be used for the final well purge or for sampling as there is a low likelihood of reducing turbidity to appropriate levels and they have the potential to strip volatiles from the water column through agitation.

To set up the pump, the check valve is screwed onto the discharge tubing where it will cut its own threads. In the case of the Waterra® pump, a surge block can also be pressed onto the check valve. The pump is lowered into the well to the screened interval and rapidly cycled up and down a distance of 3” -12”. The stroke length and speed are adjusted for pumping effect. Electric actuators can be used to reduce the effort involved. The pump should be moved to different levels in the screen to surge the entire screen. The pump can occasionally be lowered to the bottom of the well to vacuum out silt. Any silt that clogs the valve is usually quickly rinsed out by the pump cycling and if the clog remains the pump is easily retrieved and redeployed.

The surging activity is usually continued until turbidity is lowered to a measurable range and cannot easily be lowered further. Further development or purging is then conducted with other pumps.

3.8 Wells With In-Place Plumbing

Wells with in-place plumbing are commonly found at municipal water treatment plants, industrial water supplies, private residences, and in other applications. Many permanent monitoring wells at active facilities are also equipped with dedicated, in-place pumps.

A permanent monitoring well with an in-place pump may be treated as other monitoring wells without pumps. Since the in-place pump is generally “hard” mounted at a pre-selected depth, it cannot be moved up or down during purging and sampling. If the pump inlet is above the screened interval, the well should be sampled using the Multiple-Volume Purge method. If the pump intake is located within the screened interval, the well can be sampled using Low-Flow procedures. Known details of pump type and construction, tubing types, pump setting depths, and any other available information about the system should be recorded in the field logbook.

In the case of the other types of wells, e.g., municipal, industrial and residential supply wells, there is typically not enough known about the construction aspects of the wells to apply the same criteria as used for monitoring wells. The volume to be purged in these situations therefore depends on several factors: whether the pumps are running continuously or intermittently and whether or not any storage/pressure tanks are located between the sampling point and the pump. The following considerations and procedures should be followed when purging wells with in-place plumbing under the conditions described.

3.8.1 Continuously Running Pumps

If the pump runs more or less continuously, no purge (other than opening a valve and allowing it to flush for a few minutes) is necessary. If a storage tank is present, a spigot, valve or other sampling point should be found located between the pump and the storage tank. If no valve is present, locate and use the valve closest to the tank. Measurements of field parameters are recorded immediately prior to the time of sampling.

3.8.2 Intermittently or Infrequently Running Pumps

If the pump runs intermittently or infrequently, best judgment should be utilized to remove enough water from the plumbing to flush standing water from the piping and any storage tanks that might be present. Often under these conditions, 15 to 30 minutes of purging will be adequate. Measurements of pH, specific conductance, temperature and turbidity should be made and recorded at intervals during the purge and the final measurements made at the time of sampling should be considered the measurements of record for the event.

3.9 Temporary Monitoring Wells

3.9.1 General Considerations

As temporary wells are installed for immediate sample acquisition, the procedures used to purge temporary ground water monitoring wells may differ from those for permanent wells. Temporary wells include standard well screen and riser placed in boreholes created by hand augering or drilling, or they may consist of a drive rod and screen such as a direct-push Geoprobe® Screen Point that is driven into place at the desired sampling interval. As aquifer water enters the sampler immediately upon deployment, the requirement to remove several volumes of water to replace stagnant water does not necessarily apply. In practice, developing and purging the well to usable turbidity levels will remove many times the water that would be removed in a Multiple-Volume Purge with calculated well volumes. It is important to note, however, that the longer a temporary well is in place and not sampled, the more stagnant the water column becomes and the more appropriate it becomes to apply standard permanent monitoring well purging criteria to achieve representative aquifer conditions in the sample.

3.9.2 Development of Temporary Wells

In cases where the temporary well is to be sampled immediately after installation, purging is conducted primarily to mitigate the impacts of installation. In most cases, temporary well installation procedures disturb the existing aquifer conditions, causing extreme turbidity. The goal of purging is to reduce the turbidity and remove the volume of water in the area directly impacted by the installation procedure.

The following procedure has been found to be effective in developing and sampling small diameter temporary wells where a peristaltic pump can be used. Turbidity can generally be lowered to 50 NTU at the time of sampling and turbidity less than 10 NTU is often achieved.

1. Cut peristaltic tubing to reach to the bottom of the well. Connect to a peristaltic pump and begin pumping at a high rate.
2. Use the tubing to vacuum out sediment at the bottom of the well.
3. Aggressively surge the end of the tubing in the screened interval by cycling the tubing rapidly up and down. Periodically repeat vacuuming of the well bottom.
4. When a visible 'break' to a lower turbidity is observed, cease surging the well and begin lowering the pumping rate.
5. When the water clears (turbidity < 100-200 NTU) begin raising the end of the tubing to the top of the water column.
6. Continue purging from the top of the water column, lowering the pump speed as required to lower turbidity. When adequately low turbidity and stable water quality parameters have been achieved, sampling can proceed.

Where the water level is below the limit of suction in a small diameter temporary well, a Geoprobe® mechanical bladder pump can be used for purging and sampling. The well should first be developed with an inertial pump to remove the bulk of silt and suspended particles that could clog the check valves of the bladder pump. The inertial pump is used to vacuum out the bottom of the well and surged in the screened interval until a 'break' to lower turbidity is observed prior to deployment of the bladder pump. Since the mechanical bladder pump requires cumbersome redeployment to change its pumping level, it should be deployed low enough in the water column that the water level will not be lowered below the pump during purging and sampling. The mechanical bladder pump is generally deployed above the screened interval to facilitate the settling of particles, but below the top of the water column to alleviate the need to reset the pump. Detailed instructions on the deployment of the pump can be found in SESDPROC203, Pump Operation.

3.9.3 Decommissioning of Temporary Wells

After temporary wells have fulfilled their purpose, they should be properly decommissioned similar to permanent wells. In general, the casings and screens can be easily removed and the borehole should then be pressure grouted from the bottom of the original borehole to prevent surface contamination of the aquifer, cross-connection of aquifers, and to remove a potential vapor pathway.

Direct-push screen-point wells may be decommissioned by one of two methods.

1. A disposable screen is used. The sampling sheath is pulled off of the screen and a 30% solids bentonite grout is pumped down the tool string as the rods are withdrawn.

Grout volumes are measured during pumping to assure that the hole is completely filled. The disposable screen is left behind at the bottom of the borehole.

2. The screen is removed with the sampler sheath and tool string. The hole is immediately re-entered with an empty sample sheath with disposable point. Upon reaching the original total depth of the temporary well, 30% solids bentonite grout is pumped down the tool string with the pumped volume monitored during tool string withdrawal to assure that the hole is completely filled.

A system is available to insert a small diameter grouting tube down through the screen-point screen. Grout is pumped through the grouting tube while the tools are withdrawn. SESD does not use this system as grout denser than 20% solids cannot reliably be installed with this system.

Additional guidance on decommissioning may be found in SESDGUID-101, Design and Installation of Monitoring Wells.

3.9.4 Other Considerations for Direct-Push Groundwater Sampling

With certain direct push sampling techniques, such as the Hydropunch™ and other discrete samplers used with cone-penetrometer rigs, purging is either not practical or not possible. The sampling device is simply pushed or driven to the desired depth and opened, whereupon the sample is collected and retrieved. As a result, some samples collected in this way may not be satisfactory or acceptable for certain analyses, i.e., the sampler may collect a turbid sample inappropriate for metals analyses or the sample may have inadequate volume to achieve desired reporting levels.

3.10 Wells Purged to Dryness

In some situations, even with slow purge rates, a well may be purged dry in the Multiple-Volume Purge method or stable drawdown cannot be maintained in the Low-Flow method. In these cases, the well should be purged to dryness (evacuated) and sampled upon recovery of adequate volume for sampling. Sampling should occur as soon as adequate volume has recovered. The field parameters should be measured and recorded at the time of sample collection as the measurements of record for the sampling event.

Sampling under these conditions is not ideal and suitable qualifications of the data should be included in the report. Water cascading down the screen into the well may strip volatile compounds and elevate turbidity. Although suffering from other limitations, No-Purge methods may prove useful for these wells.

4 Additional Purging and Sampling Considerations

4.1 Field Care of Purging Equipment

New plastic sheeting should be placed on the ground surface around the well casing to prevent contamination of the pumps, hoses, ropes, etc., in the event they accidentally come into contact with the ground surface or, for some reason, they need to be placed on the ground during the purging event. It is preferable that hoses used in purging that come into contact with the ground water be kept on a spool or contained in a large wash tub lined with plastic sheeting, both during transportation and during field use, to further minimize contamination by the transporting vehicle or the ground surface.

Careful consideration shall be given to using submersible centrifugal or bladder pumps to purge wells which are excessively contaminated with oily compounds as it may be difficult to adequately decontaminate severely contaminated pumps under field conditions. When wells of this type are encountered, alternative equipment, such as bailers or peristaltic pumps, should be considered.

4.2 Investigation Derived Waste

Purging and field cleaning of equipment generates liquid investigation derived waste (IDW), the disposition of which must be considered. See SESD Operating Procedure for Management of Investigation Derived Waste (SESDPROC-202) for guidance on management or disposal of this waste.

4.3 Sample Preservation

After sample collection, all samples requiring preservation must be preserved as soon as practical. Consult the Analytical Services Branch Laboratory Operations and Quality Assurance Manual (ASBLOQAM) for the correct preservative for the particular analytes of interest. All samples preserved using a pH adjustment (except VOCs) must be checked, using pH strips, to ensure that they were adequately preserved. This is done by pouring a small volume of sample over the strip. Do not place the strip in the sample. Samples requiring reduced temperature storage should be placed on ice immediately.

4.4 Special Sample Collection Procedures

4.4.1 Trace Organic Compounds and Metals

Special sample handling procedures should be instituted when trace contaminant samples are being collected. All sampling equipment, including pumps, bailers, water level measurement equipment, etc., which contacts the water in the well must be cleaned in accordance with the cleaning procedures described in the SESD Operating Procedure for Field Equipment Cleaning and Decontamination (SESDPROC-205) or SESD Operating Procedure for Field Equipment Cleaning and Decontamination at the FEC (SESDPROC-

206). Pumps should not be used for sampling unless the interior and exterior portions of the pump and the discharge hoses are thoroughly cleaned. Rinse blank samples should be collected to verify the adequacy of cleaning when using a sampling pump other than a peristaltic pump.

4.4.2 Order of Sampling with Respect to Analytes

In many situations when sampling permanent or temporary monitoring wells, sufficiently low turbidity is difficult to achieve and maintain. Removal and insertion of equipment after the purge or during sampling may negate the low turbidities achieved during purging and elevate turbidity back to unacceptable levels. For this reason, it is important that special efforts be used to minimize any disturbance of the water column after purging and to fill sample containers for metals analysis first. The preferred order of sampling is metals first, followed by other inorganic analytes, extractable organic compounds, and finally volatile organic compounds.

4.5 Filtering

As many contaminants are known to sorb to soil particles, the normal goal of sampling is to reduce the presence of these particles (measured by turbidity) in order that the dissolved concentration of contaminants can be obtained. However, transport of sorbed contamination on colloidal particles can be a means of contaminant transport on some sites. For this reason, the SESD approach is to reduce turbidity through the careful purging of wells, rather than through filtering of samples, in order that the colloidal particles would be included in the sample.

As a standard practice, ground water samples will not be filtered for routine analysis. Filtering will usually only be performed to determine the fraction of major ions and trace metals passing the filter and used for flow system analysis and for the purpose of geochemical speciation modeling. Filtration is not acceptable to correct for improperly designed or constructed monitoring wells, inadequate well development, inappropriate sampling methods, or poor sampling technique.

When samples are collected for routine analyses and are filtered, both filtered and non-filtered samples will be submitted for analyses. Samples for organic compounds analysis should not be filtered. Prior to filtration of the ground water sample for any reason other than geochemical speciation modeling, the following criteria must be demonstrated to justify the use of filtered samples for inorganic analysis:

1. The monitoring wells, whether temporary or permanent, have been constructed and developed in accordance with the SESD Guidance Document, Design and Installation of Monitoring Wells (SESDGUID-001).

2. The ground water samples were collected using sampling techniques in accordance with this section, and the ground water samples were analyzed in accordance with USEPA approved methods.

3. Efforts have been undertaken to minimize any persistent sample turbidity problems. These efforts may consist of the redevelopment or re-installation of permanent ground water monitoring wells or the implementation of carefully conducted low flow rate sampling techniques.

If filtration is necessary for purposes of geochemical modeling or other **pre-approved** cases, the following procedures are suggested:

1. Accomplish in-line filtration through the use of disposable, high capacity filter cartridges (barrel-type) or membrane filters in an in-line filter apparatus. The high capacity, barrel-type filter is preferred due to the higher surface area associated with this configuration. If a membrane filter is utilized, a minimum diameter of 142 mm is suggested.

2. When using pumps for sampling, the filter can generally be attached directly to the pump outlet. When sampling with a bailer or when otherwise required, an initial unfiltered sample with extra volume will be collected, and a peristaltic pump with filter used to decant and filter the sample to the final sample container.

3. Use a 0.45 µm pore-size filter to remove most non-dissolved particles. A 5 µm or 10 µm pore-size filter should be used for the purpose of determining colloidal constituent concentrations.

4. Fill the filter and rinse with approximately one additional filter volume prior to filling sample bottles

Potential differences can result from variations in filtration procedures used to process water samples for the determination of trace element concentrations. A number of factors associated with filtration can substantially alter "dissolved" trace element concentrations; these include filter pore size, filter type, filter diameter, filtration method, volume of sample processed, suspended sediment concentration, suspended sediment grain-size distribution, concentration of colloids and colloidally-associated trace elements, and concentration of organic matter. Therefore, consistency is critical in the comparison of short-term and long-term results. Further guidance on filtration may be obtained from the following: 1) Metals in Ground Water: Sampling Artifacts and Reproducibility; 2) Filtration of Ground Water Samples for Metals Analysis; and 3) Ground Water Sampling - A Workshop Summary. See Section 1.4, References, for complete citation for these documents.

4.6 Bacterial Sampling

Whenever wells (normally potable wells) are sampled for bacteriological parameters, care must be taken to ensure the sterility of all sampling equipment and all other equipment entering the well. Further information regarding bacteriological sampling is available in the following: 1) Sampling for Organic Chemicals and Microorganisms in the Subsurface; 2) Handbook for Evaluating Water Bacteriological Laboratories; and 3) Microbiological Methods for Monitoring the Environment, Water and Wastes. See Section 1.4, References, for complete citation for these documents.

4.7 Specific Sampling Equipment Quality Assurance Techniques

All equipment used to collect ground water samples shall be cleaned as outlined in the SESD Operating Procedure for Field Equipment Cleaning and Decontamination (SESDPROC-205) or SESD Operating Procedure for Field Equipment Cleaning and Decontamination at the FEC (SESDPROC-206). Malfunctioning equipment should be labeled in the field and repaired, before being stored at the conclusion of field studies. Cleaning procedures utilized in the field or field repairs shall be thoroughly documented in field records.

4.8 Auxiliary Data Collection

During ground water sample collection, it is important to record a variety of ground water related data. Included in the category of auxiliary data are water levels measured according to the SESD Operating Procedure for Groundwater Level and Well Depth Measurement (SESDPROC-105), well volume determinations, pumping rates during purging, and, driller or boring logs. This information should be documented in the field records.

4.9 Well Development

Wells may be encountered that are difficult to sample effectively due to inadequate initial development or the need for redevelopment due to scaling, sedimentation, corrosion, or biofouling. These wells may produce water only at low flow rates or water with chronically elevated turbidity. Redevelopment of these wells should be considered as the process can improve sample quality and speed field operations. Well development procedures are described in Design and Installation of Monitoring Wells (SESDGUID-101).

APPENDIX D

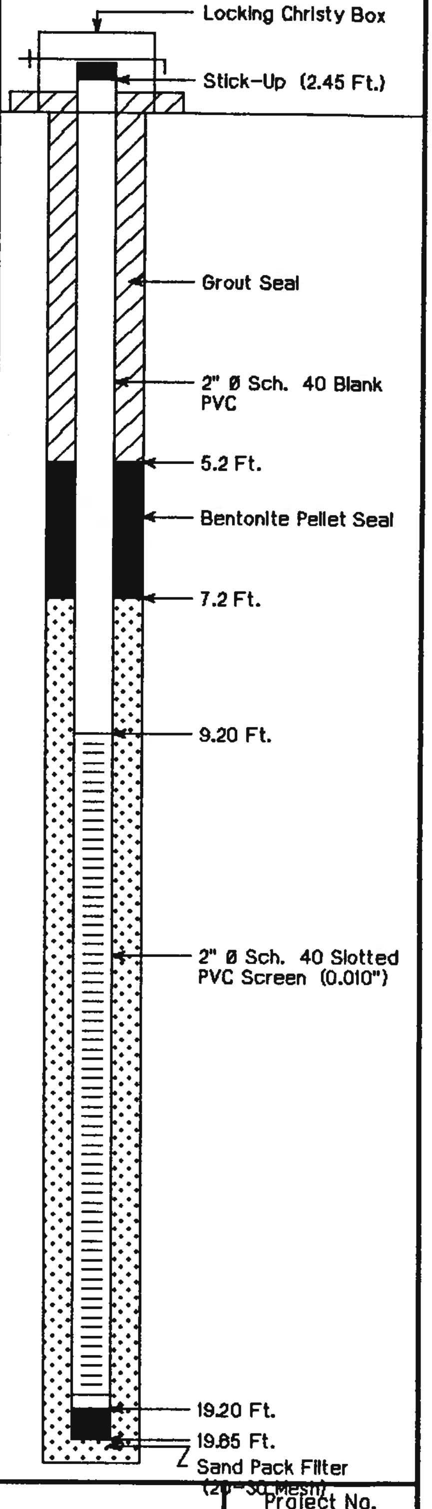
Existing Well Boring Logs and Well Construction Diagrams

Monitoring Well No. PMW-17

PROJECT: KEMIRA DEPTFORD SITE
DATE: 5/4/95
LOGGED BY: TONY L. GORDON
DRILL RIG: Hollow Stem Auger
HOLE DIA.: 8 in.
SAMPLER: SPLIT-SPOON
INITIAL GW DEPTH: 8.16 ft.
FINAL GW: 5.61 ft.
HOLE ELEV.: 13.83 FT. MSL

DESCRIPTION	USCS CLASS	DEPTH	BLOWS/FT.
Orange to brown, black, SILT and very fine SAND, trace to little clay, trace pebble size gravel; non plastic; medium stiff; moist (fill).	SM ML	0 – 4	7 5 6 7 5 6
Dark gray, black, organically rich, silty CLAY, trace very fine to fine sand; low plasticity; very soft; moist. Final groundwater elevation (5/4/95). ▼	OL	4 – 14	2 1 1 1 1 1 1 1 1 1 1 1 1 1 1
Gray, grayish green, silty, CLAY and fine SAND; low plasticity, medium stiff; wet. Boring terminated at 20 feet.	SC	14 – 20	4 4 5 5 5 7 7 6 7

WELL CONSTRUCTION DETAIL



AEM

Environmental Consultants
Atlanta, Georgia

Notes:

1. USCS = Unified Soil Classification. 2. Measurements are from ground surface.

Project No.
94-458-01

Page 1 of 1

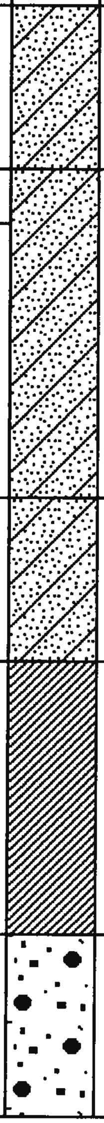
Boring Log: *MW-19B*

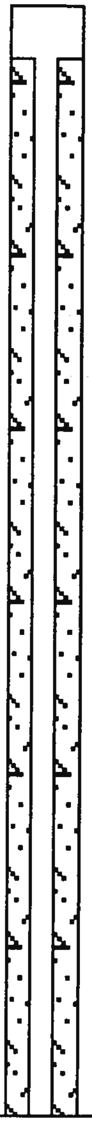
Project: Kerr-McGee
Project No.: 558909/03
Location: Savannah, GA
Completion Date: 3/5/02

Surface Elevation (feet AMSL*): 6.79
TOC Elevation (feet AMSL*): 6.80
Total Depth (feet): 40'
Borehole Diameter (inches): 2"

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Description**
					Ground Surface
0 2	1	0			***Sand (SC)*** Topsoil/Fill. Medium brown, dry to moist, medium grained sands with some white clays (plastic). No odor.
	2	0			***Sand (SC)*** Sand dark brown to black sand with clay, some gravel, micaceous fine to medium grained. Loose. No odor.
4 6 8	3	0			
10	4	0			***Sand (SC)*** Clayey sand. Dark grey with clay. Plastic, wet. Wood fragment. Fine sands.
12 14 16	5	0			***Clay (CH)*** Greenish/grey very plastic, clay. Trace fine sands. Moist. No odor.
18 20					***Sand (SP)*** Grey to greenish medium to coarse grained sands. Little to no fines. Poorly sorted. Wet. Micaceous. No odor.





Geologist(s): CBM
Subcontractor: Prosonic
Driller/ Operator: Fred, Chuck, Vern

Method: **HSA** ☐ **Geoprobe** ☐ **ID(inches):** **Rotosonic** ☑

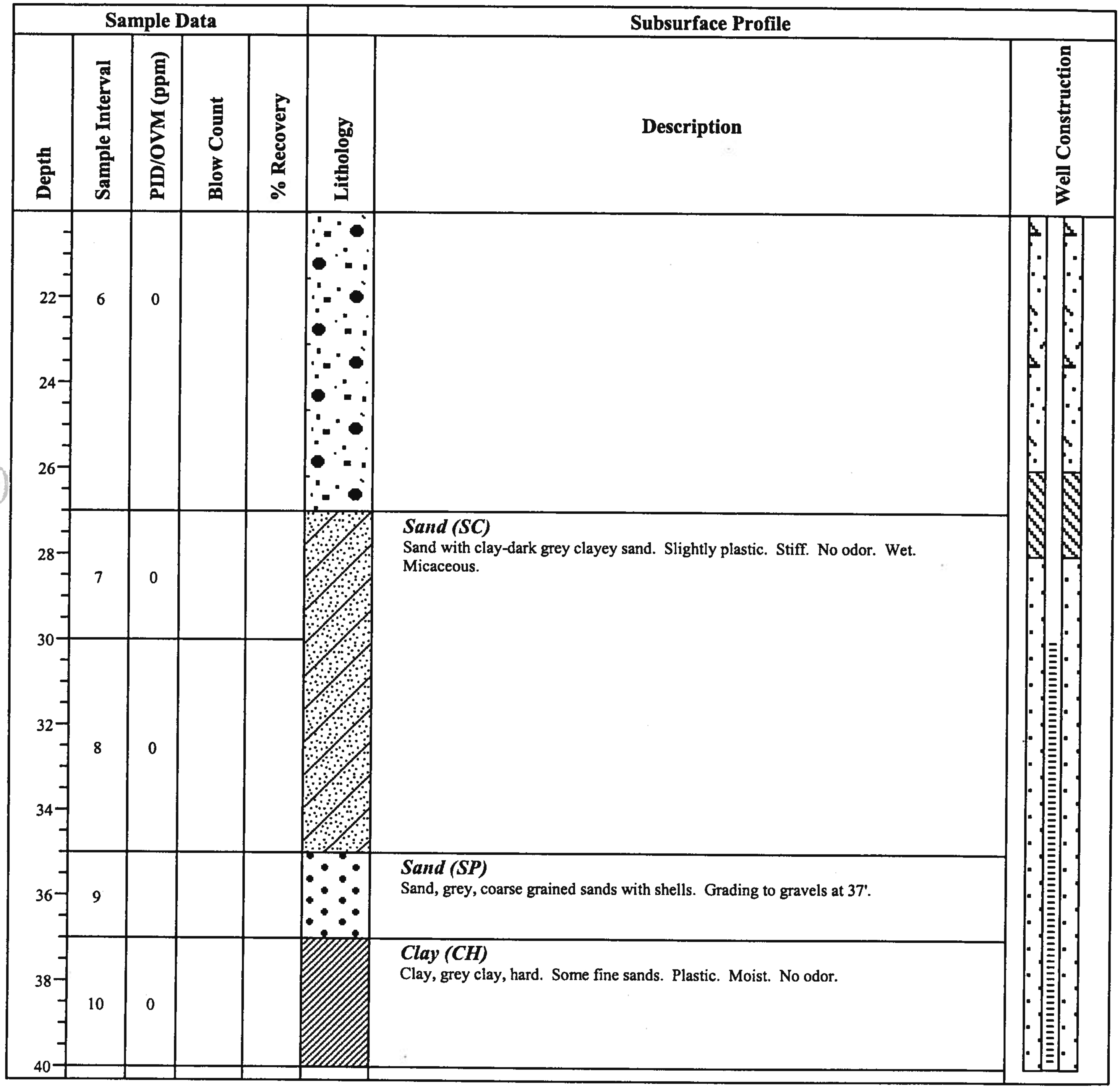
** AMSL= Above mean sea level*

Boring Log:* *MW-19B

Project: Kerr-McGee
Project No.: 558909/03
Location: Savannah, GA
Completion Date: 3/5/02

Surface Elevation (feet AMSL*): 6.79
TOC Elevation (feet AMSL*): 6.80
Total Depth (feet): 40'
Borehole Diameter (inches): 2"

ENVIRONMENTAL
STRATEGIES



Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
22 24 26	6	0					
28	7	0				***Sand (SC)*** Sand with clay-dark grey clayey sand. Slightly plastic. Stiff. No odor. Wet. Micaceous.	
30 32 34	8	0					
36	9					***Sand (SP)*** Sand, grey, coarse grained sands with shells. Grading to gravels at 37'.	
38 40	10	0				***Clay (CH)*** Clay, grey clay, hard. Some fine sands. Plastic. Moist. No odor.	

Geologist(s): CBM
Subcontractor: Prosonic
Driller/ Operator: Fred, Chuck, Vern

Method: **HSA** ☐ **Geoprobe** ☐ **ID(inches):** **Rotosonic** ☑

** AMSL= Above mean sea level*

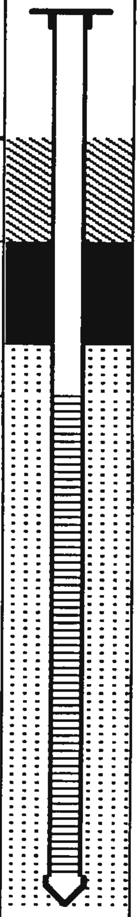
Boring Log: PZ-1A

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 13, 2003

Surface Elevation (feet AMSL*): 8.866
TOC Elevation (feet AMSL*): 10.956
Total Depth (feet): 15
Borehole Diameter (inches): 8.25

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
-3							
-1						Ground Surface	
1						***FILL (FL)*** gravel	
3	1	0		80%		***Red Brown to Tan SAND (SP)*** fine- to medium-grained, well sorted sand; moist	
5						***Grey CLAY (OH) - MUCK*** saturated	
7	2	0		100%			
9							
11							
13	3	0		100%			
15							
17							



Geologist(s): JFM
Subcontractor: Boart-Longyear
Driller/ Operator: M. Mueller

Method: HSA ☑ Geoprobe ☐ **ID(inches):** 2 Rotosonic ☐

** AMSL= Above mean sea level*

Boring Log: PZ-1B

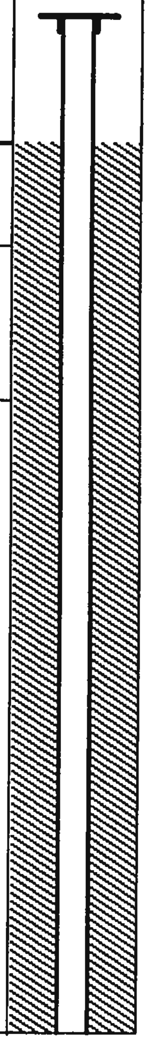
Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 13, 2003

Surface Elevation (feet AMSL*): 8.866
TOC Elevation (feet AMSL*): 11.038
Total Depth (feet): 45
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile	
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**
-3						
-1						Ground Surface
1					●	***FILL (FL)*** gravel
3	1	0		80%	░	***Red Brown to Tan SAND (SP)*** fine- to medium-grained, well sorted sand; moist
5					▨	***Grey CLAY (OH) - MUCK*** saturated
7	2	0		100%	▨	
9					▨	
11					▨	
13	3	0		100%	▨	
15					▨	
17					▨	

Well Construction



Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: HSA ☐ Geoprobe ☐ Rotosonic ☑
ID(inches): 2

** AMSL= Above mean sea level*

Boring Log: PZ-1B

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 13, 2003

Surface Elevation (feet AMSL*): 8.866
TOC Elevation (feet AMSL*): 11.038
Total Depth (feet): 45
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
19	4	0		0%	▨		▨
21 23	5	0		0%	▨		▨
25 27 29	6	0		100%	▨		▨
31 33	7	0		100%	▨ ⁘	***Grey SAND (SW)*** fine- to coarse-grained sand; saturated	▨ ■ ⁘
35 37					⁘		⁘

Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: **HSA** ☐ **Geoprobe** ☐ **Rotosonic** ☑
ID(inches): 2

** AMSL= Above mean sea level*

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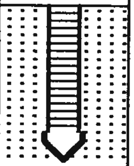
ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
	8	0		100%	⁘		
39					▨	*Green Silty CLAY (CL) - HAWTHORNE* dense, moist	
41					▨		
43	9	0		100%	▨		
45							
47							
49							
51							
53							
55							
57							

Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: **HSA** ☐ **Geoprobe** ☐ **Rotosonic** ☑ **ID(inches):** 2

** AMSL= Above mean sea level*

Boring Log: PZ-2A

Project: Kerr-McGee

Project No.: 558908

Location: Savannah, GA

Completion Date: May 17, 2003

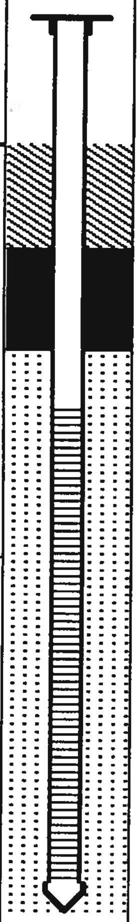
Surface Elevation (feet AMSL*): 9.524

TOC Elevation (feet AMSL*): 11.892

Total Depth (feet): 15

Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
-3 -1						Ground Surface	
1 3	1	0			●	***Brown to Grey Silty Sand FILL (FL)*** silty sand grading to medium- to coarse-grained quartz sand	
5 7	2A	4.6			●		
9 11 13	2B	14.8			▨	***Dark Greenish Grey Silty CLAY (OH) MUCK*** organic rich, slightly stiff, plastic; moist, strong acidic sulfur odor, PID = 15 ppm	
15 17							

Geologist(s): JFM

Subcontractor: Boart-Longyear

Driller/ Operator: R. Buckenberge

Method: HSA ☐ Geoprobe ☐

ID(inches): 2

Rotosonic ☑

** AMSL= Above mean sea level*

Boring Log: PZ-2B

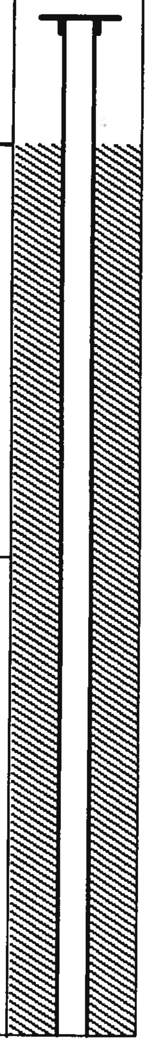
Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 17, 2003

Surface Elevation (feet AMSL*): 9.524
TOC Elevation (feet AMSL*): 12.161
Total Depth (feet): 45
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile	
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**
-3						
-1						
						Ground Surface
1					⁘	***Brown to Grey Silty Sand FILL (FL)*** silty sand grading to medium- to coasre-grained quartz sand
3	1	0			⁘	
5					⁘	
7	2A	4.6			⁘	
9					▨	***Dark Greenish Grey Silty CLAY (OH) MUCK*** organic rich, slightly stiff, plastic; moist, strong acidic sulfur odor, PID = 15 ppm
11	2B	14.8			▨	
13					▨	
15					▨	
17	3A	7.8			▨	

Well Construction



Geologist(s): JFM
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: HSA ☐ Geoprobe ☐ Rotosonic ☑
ID(inches): 2

** AMSL= Above mean sea level*

Boring Log: PZ-2B

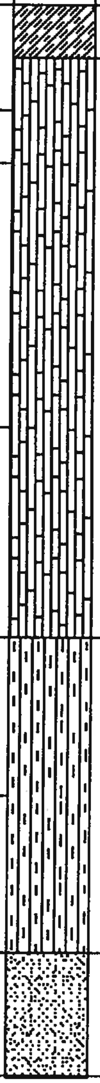
Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 17, 2003

Surface Elevation (feet AMSL*): 9.524
TOC Elevation (feet AMSL*): 12.161
Total Depth (feet): 45
Borehole Diameter (inches): 6

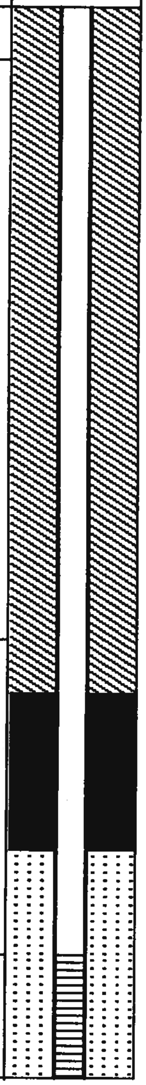
ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Description**
19	3B	0			***Grey SILTY SAND (SM)*** silty, fine- to coarse-grained quartz sand; loose, soft, wet, PID = 0ppm
21 23	3C	0			
25 27	4A	0			
29 31	4B	0			***Grey Silty CLAY (OM)*** with interbedded sand lenses and large organic fragments
33	4C	0			
35 37					***Light Grey to Greenish Brown SAND (SP)*** coarse gravelly sand transitioning to silty with depth; wet

Lithology



Well Construction



Geologist(s): JFM
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: HSA ☐ Geoprobe ☐ Rotosonic ☑

ID(inches): 2

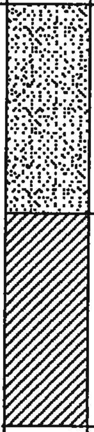
** AMSL= Above mean sea level*

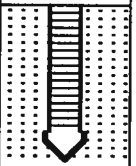
Boring Log: PZ-2B

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 17, 2003

Surface Elevation (feet AMSL*): 9.524
TOC Elevation (feet AMSL*): 12.161
Total Depth (feet): 45
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES





Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
39							
41						***Dark Greenish Grey Sandy CLAY (CL) - HAWTHORNE*** sandy/silty Hawthorne clay; hard, dense, dry	
43							
45							
47							
49							
51							
53							
55							
57							

Geologist(s): JFM
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: **HSA** ☐ **Geoprobe** ☐ **ID(inches):** 2 **Rotosonic** ☑

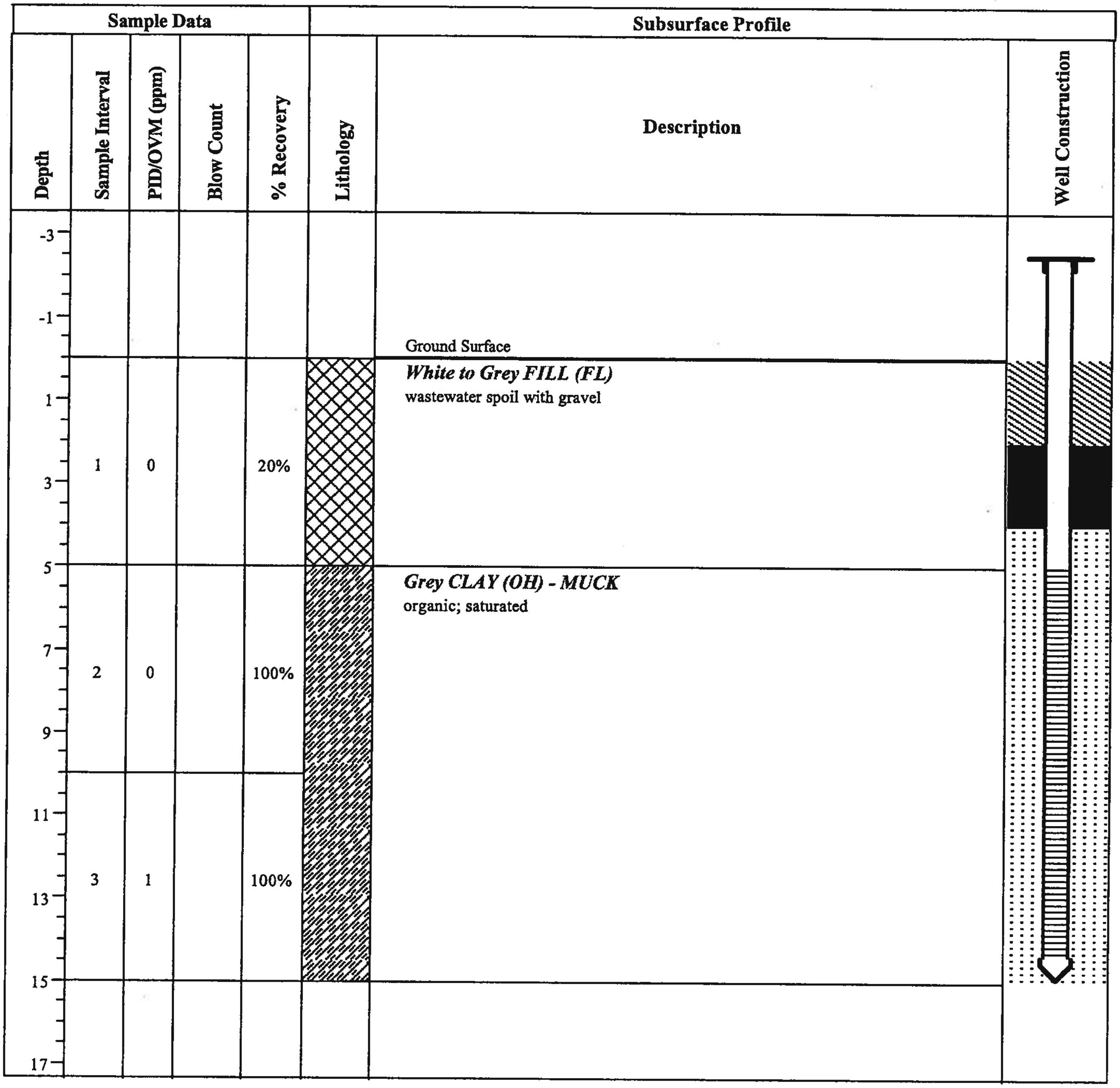
** AMSL= Above mean sea level*

Boring Log:* *PZ-3A

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 16, 2003

Surface Elevation (feet AMSL*): 7.554
TOC Elevation (feet AMSL*): 9.631
Total Depth (feet): 15
Borehole Diameter (inches): 8.25

ENVIRONMENTAL STRATEGIES



Sample Data					Subsurface Profile	
Depth	Sample Interval	PID/OVM (ppm)	Blow Count	% Recovery	Lithology	Description
						Ground Surface
	1	0		20%		***White to Grey FILL (FL)*** wastewater spoil with gravel
	2	0		100%		***Grey CLAY (OH) - MUCK*** organic; saturated
	3	1		100%		

Geologist(s): JFM
Subcontractor: Boart-Longyear
Driller/ Operator: M. Mueller

Method: **HSA** ☑ **Geoprobe** ☐ **ID(inches):** 2 **Rotosonic** ☐

** AMSL= Above mean sea level*

Boring Log: ***PZ-3B***

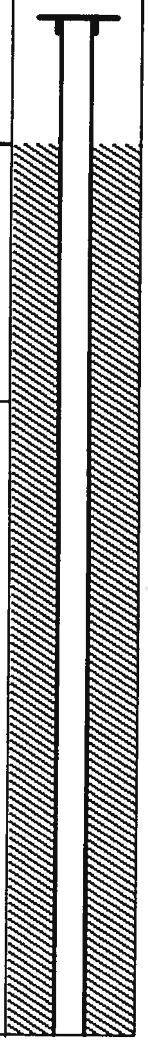
Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 16, 2003

Surface Elevation (feet AMSL*): 7.554
TOC Elevation (feet AMSL*): 9.889
Total Depth (feet): 55
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile	
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**
-3						
-1						
						Ground Surface
1						***White to Grey FILL (FL)*** wastewater spoil with gravel
3	1	0		20%		
5						***Grey CLAY (OH) - MUCK*** organic; saturated
7	2	0		100%		
9						
11						
13	3	1.2		100%		
15						
17						

Well Construction



Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: HSA ☐ Geoprobe ☐ Rotosonic ☑
ID(inches): 2

** AMSL= Above mean sea level*

Boring Log: PZ-3B

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 16, 2003

Surface Elevation (feet AMSL*): 7.554
TOC Elevation (feet AMSL*): 9.889
Total Depth (feet): 55
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
19	4	NR		0	▨		
21 23	5	NR		0	▨		
25 27 29	6	2.5		100%	▨		
31 33	7	3.1		100%	░	***Grey to Buff SAND (SM/SP)*** fine- to coarse-grained sand; silty at top, saturated	
35 37					░		

Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: **HSA** ☐ **Geoprobe** ☐ **ID(inches):** 2 **Rotosonic** ☑

** AMSL= Above mean sea level*

Boring Log: PZ-3B

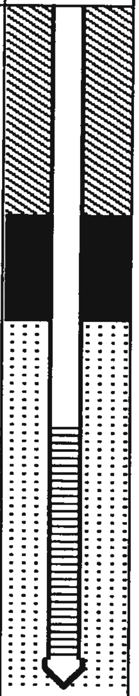
Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 16, 2003

Surface Elevation (feet AMSL*): 7.554
TOC Elevation (feet AMSL*): 9.889
Total Depth (feet): 55
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Depth	Sample Interval	PID/OVM (ppm)	Blow Count	% Recovery	Lithology	Description
39	8	2.4		100%	░	
41, 43	9	3.3		100%	░	
45, 47, 49	10	1.3		30%	░	
51, 53	11	---		30%	░	
55					▨	***Greenish Grey Silty CLAY (CL) - HAWTHORNE*** dense, moist
57						

Well Construction



Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: HSA ☐ Geoprobe ☐ Rotosonic ☑
ID(inches): 2

** AMSL= Above mean sea level*

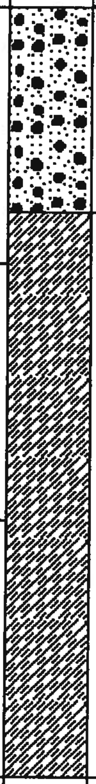
Boring Log: W-1A

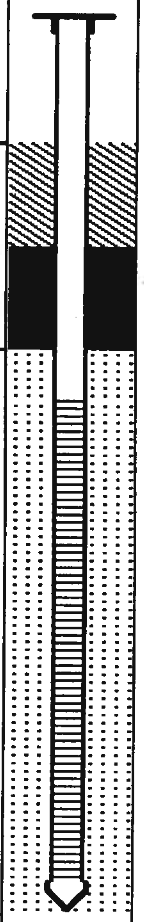
Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 13, 2003

Surface Elevation (feet AMSL*): 8.506
TOC Elevation (feet AMSL*): 10.734
Total Depth (feet): 15
Borehole Diameter (inches): 8.25

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
-3							
-1						Ground Surface	
1						***Reddish Brown FILL (FL)*** moist, fine-grained sandy fill	
3	1			60%			
5						***Grey CLAY (OH) - MUCK*** moist to saturated	
7	2			0%			
9							
11							
13	3			0%			
15							
17							





Geologist(s): JFM
Subcontractor: Boart-Longyear
Driller/ Operator: M. Mueller

Method: HSA ☑ Geoprobe ☐ ID(inches): 2 Rotosonic ☐

** AMSL= Above mean sea level*

Boring Log: W-1B

Project: Kerr-McGee

Project No.: 558908

Location: Savannah, GA

Completion Date: May 13, 2003

Surface Elevation (feet AMSL*): 8.506

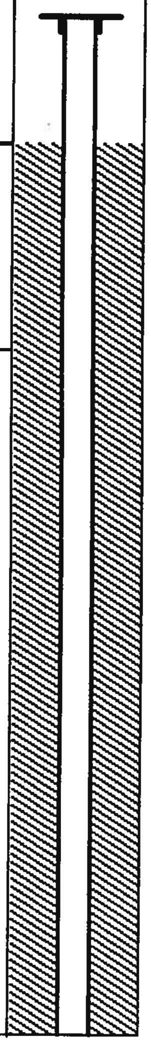
TOC Elevation (feet AMSL*): 10.637

Total Depth (feet): 55

Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
-3							
-1						Ground Surface	
1	1	0		60%	⁘	***Reddish Brown FILL (FL)*** moist, fine-grained sandy fill	
3					⁘		
5	2	0		0%	▨	***Grey CLAY (OH) - MUCK*** moist to saturated	
7					▨		
9					▨		
11	3	0		0%	▨		
13					▨		
15					▨		
17					▨		



Geologist(s): DRL

Subcontractor: Boart-Longyear

Driller/ Operator: R. Buckenberge

Method: HSA ☐ Geoprobe ☐ Rotosonic ☑

ID(inches): 2

** AMSL= Above mean sea level*

Boring Log: W-1B

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 13, 2003

Surface Elevation (feet AMSL*): 8.506
TOC Elevation (feet AMSL*): 10.637
Total Depth (feet): 55
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
19	4	0		20%	▨		▨
21					▨		▨
23	5	0		20%	▨		▨
25					▨		▨
27	6	0		100%	░	***Grey SAND (SP)*** fine- to medium-grained sand with interbedded clay lenses up to 3.5 inches thick; saturated	▨
29					░		▨
31					░		▨
33	7	0		100%	░		▨
35					░		▨
37					░		▨

Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: HSA ☐ Geoprobe ☐ Rotosonic ☑
ID(inches): 2

** AMSL= Above mean sea level*

Boring Log: W-1B

Project: Kerr-McGee

Project No.: 558908

Location: Savannah, GA

Completion Date: May 13, 2003

Surface Elevation (feet AMSL*): 8.506

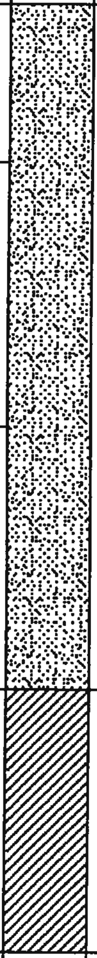
TOC Elevation (feet AMSL*): 10.637

Total Depth (feet): 55

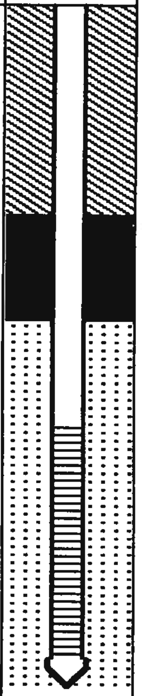
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile	
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**
39	8	0		100%		
41 43	9	0		100%		
45 47 49	10	0		100%		
51 53	11	0		100%		*Green Silty Clay (CL) - HAWTHORN* saturated
55 57						



Well Construction



Geologist(s): DRL

Subcontractor: Boart-Longyear

Driller/ Operator: R. Buckenberge

Method: HSA ☐ Geoprobe ☐

ID(inches): 2

Rotosonic ☑

** AMSL= Above mean sea level*

Boring Log:* *W-3A

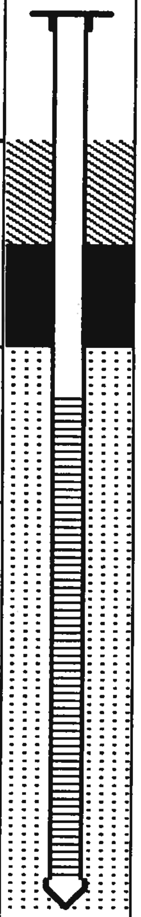
Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 14, 2003

Surface Elevation (feet AMSL*): 9.040
TOC Elevation (feet AMSL*): 11.626
Total Depth (feet): 15
Borehole Diameter (inches): 8.25

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile	
Depth	Sample Interval	PID/OVM (ppm)	Blow Count	% Recovery	Lithology	Description
-3						
-1						Ground Surface
1						*Grey Clayey Process Materials (FL)* saturated - slight odor
3	1	0		40%		
5						*Grey FIll (FL)* medium-grained sand; saturated
7	2	0		100%		*Grey CLAY (OH) - MUCK* organic; saturated
9						
11						
13	3	0		100%		
15						
17						

Well Construction



Geologist(s): JFM
Subcontractor: Boart-Longyear
Driller/ Operator: M. Mueller

Method: **HSA** ☑ **Geoprobe** ☐ **ID(inches):** 2 **Rotosonic** ☐

** AMSL= Above mean sea level*

Boring Log: ***W-3B***

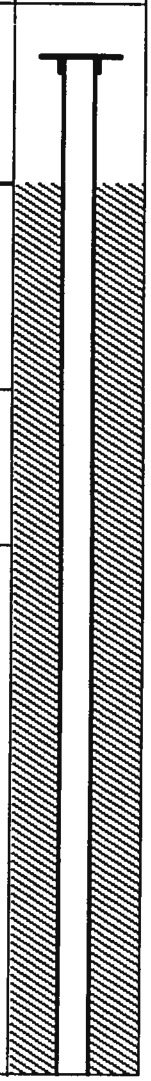
Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 14, 2003

Surface Elevation (feet AMSL*): 9.040
TOC Elevation (feet AMSL*): 11.623
Total Depth (feet): 45
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile	
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**
-3						
-1						Ground Surface
1					▩	***Grey Clay Process Materials (FL)*** saturated - slight odor
3	1	0		40%	▩	
5					⁙	***Grey FIll (FL)*** medium-grained sand; saturated
7	2	0		100%	▨	***Grey CLAY (OH) - MUCK*** organic; saturated
9					▨	
11					▨	
13	3	0		100%	▨	
15					▨	
17					▨	

Well Construction



Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: HSA ☐ Geoprobe ☐ Rotosonic ☑
ID(inches): 2

** AMSL= Above mean sea level*

Boring Log: W-3B

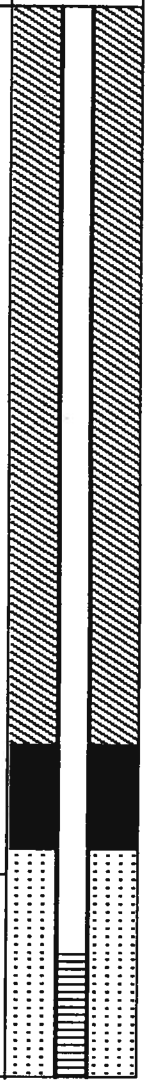
Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 14, 2003

Surface Elevation (feet AMSL*): 9.040
TOC Elevation (feet AMSL*): 11.623
Total Depth (feet): 45
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile	
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**
19	4	0		100%	▨	
21 23	5	0		100%	▨	
25 27 29	6	0		100%	▨	
31 33	7	0		100%	▨ ⁘	*Grey SAND (SW)* well-graded, fine- to coarse-grained sand; saturated
35 37					⁘	

Well Construction



Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: **HSA** ☐ **Geoprobe** ☐ **Rotosonic** ☑ **ID(inches):** 2

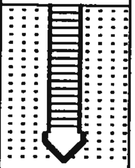
** AMSL= Above mean sea level*

Boring Log:* *W-3B

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 14, 2003

Surface Elevation (feet AMSL*): 9.040
TOC Elevation (feet AMSL*): 11.623
Total Depth (feet): 45
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
39	8	0		100%	░		
41 43	9	0		100%	▨	***Brownish Green Silty CLAY (CL) - HAWTHORNE*** dense, organic clayey silt	
45 47 49 51 53 55 57							

Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: **HSA** ☐ **Geoprobe** ☐ **ID(inches):** 2 **Rotosonic** ☑

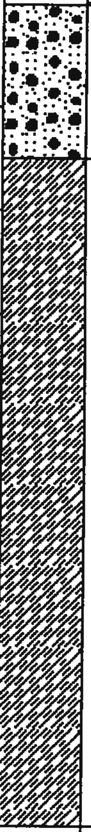
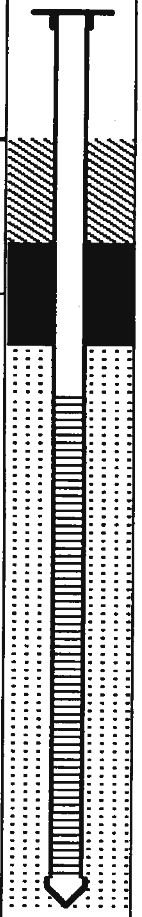
* *AMSL= Above mean sea level*

Boring Log: *W-4A*

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 15, 2003

Surface Elevation (feet AMSL*): 7.516
TOC Elevation (feet AMSL*): 10.004
Total Depth (feet): 16
Borehole Diameter (inches): 8.25

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	Sample Interval	PID/OVM (ppm)	Blow Count	% Recovery	Lithology	Description	Well Construction
-3							
-1						Ground Surface	
1						***Brown and Grey Silty Sand FILL (FL)*** silty/clayey, fine- to medium-grained sand; damp	
3	1	0	1 1 1 1	100%		***Greenish Grey to Black Clayey SILT (OH) - MUCK*** highly organic with large organic matter; damp to wet, soft	
5	2	0	1 1 1 1	100%			
7	3	0	1 1 1 1	100%			
9	4	0	1 1 1 1	92%			
11	5	0	1 1 1 1	75%			
13	6	0	1 1 1 1	100%			
15	7	0	1 1 1 1	100%			
17							

Geologist(s): JFM
Subcontractor: Boart-Longyear
Driller/ Operator: M. Mueller

Method: HSA ☑ Geoprobe ☐ Rotosonic ☐

ID(inches): 2

** AMSL= Above mean sea level*

Boring Log: W-4B

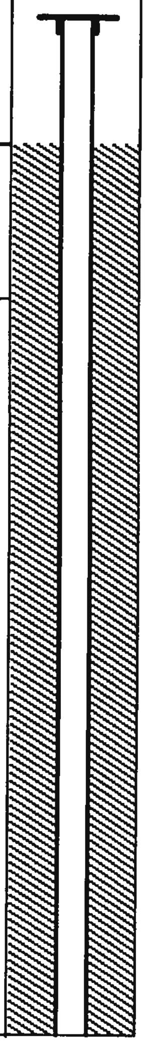
Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 14, 2003

Surface Elevation (feet AMSL*): 7.516
TOC Elevation (feet AMSL*): 10.004
Total Depth (feet): 55
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile	
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**
-3						
-1						Ground Surface
1					⁘	***FILL (FL)*** 4 inches of concrete over sand and gravel fill
3	1	0		100%	▨	***Black to Grey CLAY (OH) - MUCK*** organic; moist to saturated
5					▨	
7	2	NR		0%	▨	
9					▨	
11					▨	
13	3	NR		0%	▨	
15					▨	
17					▨	

Well Construction



Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: HSA ☐ Geoprobe ☐ Rotosonic ☑
ID(inches): 2

** AMSL= Above mean sea level*

Boring Log: W-4B

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 14, 2003

Surface Elevation (feet AMSL*): 7.516
TOC Elevation (feet AMSL*): 10.004
Total Depth (feet): 55
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
19 21 23	4	NR		0%	▨		▨ ▨
25 27 29	5	0		10%	▨		▨ ▨
31 33	6	0		60%	░	*Grey SAND (SP)* well-sorted, medium- to coarse-grained sand; saturated	▨ ▨
35 37					░		▨ ▨

Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: **HSA** ☐ **Geoprobe** ☐ **ID(inches):** 2 **Rotosonic** ☑

** AMSL= Above mean sea level*

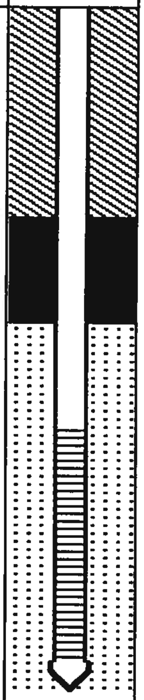
Boring Log:* *W-4B

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 14, 2003

Surface Elevation (feet AMSL*): 7.516
TOC Elevation (feet AMSL*): 10.004
Total Depth (feet): 55
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
39	7	0		100%	▒		
41 43	8	0		100%	▒		
45 47 49	9	0		90%	▒		
51 53 55	10	0		90%	▒ ▨	***Greenish Grey Silty CLAY (CL) - HAWTHORNE*** clayey silt; moist	
57							



Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: **HSA** ☐ **Geoprobe** ☐ **ID(inches):** 2 **Rotosonic** ☑

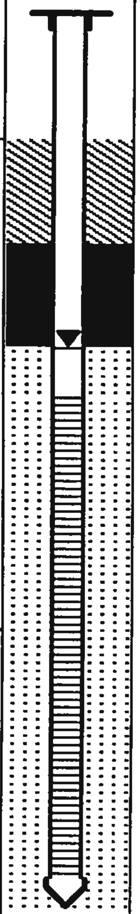
** AMSL= Above mean sea level*

Boring Log:* *W-7A

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 14, 2003

Surface Elevation (feet AMSL*): 10.446
TOC Elevation (feet AMSL*): 12.761
Total Depth (feet): 14
Borehole Diameter (inches): 8.25

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	Sample Interval	PID/OVM (ppm)	Blow Count	% Recovery	Lithology	Description	Well Construction
-3							
-1						Ground Surface	
1	1	---		67%	●	***Grey to Brown Silty Sand FILL (FL)*** silty, fine- to coarse-grained sand with rounded gravel; dry to wet, strong sulfur odor	
3	2	0	2 4 3 4	58%	●		
5	3	0	2 3 5 4	50%	●		
7	4	7.8	1 1 1 1	50%	●		
9	5	10.6	1 1 1 1	90%	●		
11	6	---	1 1 1 2	50%	▨	***Grey to Black Silty CLAY (OH) - MUCK*** organic-rich; wet, stiff, plastic, sulfur odor	
13	7	---	1 1 1 6	75%	▨		
15							
17							

Geologist(s): JFM
Subcontractor: Boart-Longyear
Driller/ Operator: M. Mueller

Method: HSA ☑ Geoprobe ☐ **ID(inches):** 2 Rotosonic ☐

** AMSL= Above mean sea level*

Boring Log:* *W-9A

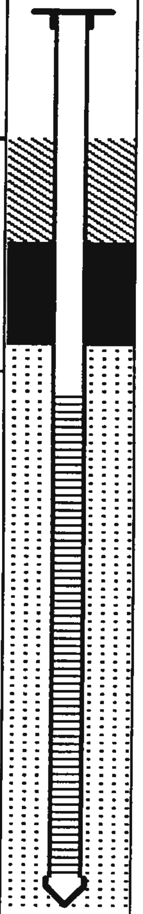
Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 15, 2003

Surface Elevation (feet AMSL*): 9.435
TOC Elevation (feet AMSL*): 12.120
Total Depth (feet): 14
Borehole Diameter (inches): 8.25

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile	
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**
-3						
-1						Ground Surface
1	1	---	3 2 6 6	63%	●	***Reddish Brown Silty Sand FILL (FL)*** silty, fine- to coarse-grained sand with some gravel; loose, moist to wet
3	2	---	3 2 2 2	63%	●	
5	3	---	1 1 1 1	100%	▨	***Black to Greenish Grey Clayey SILT (OH) - MUCK*** large organic fragments; wet, soft
7	4	---	1 1 1 1	50%	▨	
9	5	---	1 1 1 1	17%	▨	
11	6	0	1 1 1 1	83%	▨	
13	7	0	1 1 1 1	100%	▨	
15						
17						

Well Construction



Geologist(s): JFM
Subcontractor: Boart-Longyear
Driller/ Operator: M. Mueller

Method: HSA ☑ Geoprobe ☐ **ID(inches):** 2 Rotosonic ☐

** AMSL= Above mean sea level*

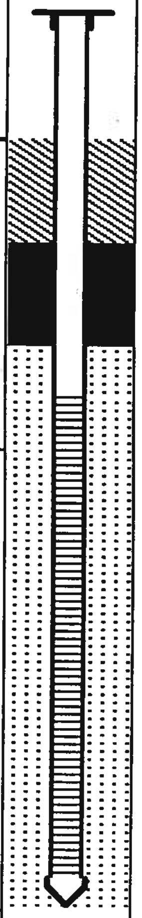
Boring Log:* *W-18A

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 15, 2003

Surface Elevation (feet AMSL*): 8.898
TOC Elevation (feet AMSL*): 11.257
Total Depth (feet): 15
Borehole Diameter (inches): 8.25

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
-3							
-1						Ground Surface	
1					●	***Grey to Brown FILL (FL)*** gravel and medium-grained sand	
3	1	0		15%	●		
5					●		
7	2	0		100%	▨	***Grey CLAY (OH) - MUCK*** organic; saturated	
9					▨		
11					▨		
13	3	0		100%	▨		
15							
17							



Geologist(s): JFM
Subcontractor: Boart-Longyear
Driller/ Operator: M. Mueller

Method: HSA ☑ Geoprobe ☐ **ID(inches):** 2 Rotosonic ☐

** AMSL= Above mean sea level*

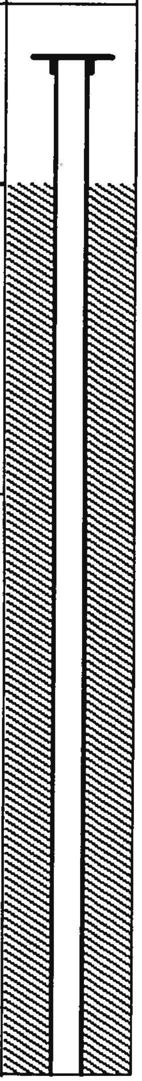
Boring Log: W-18B

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 14, 2003

Surface Elevation (feet AMSL*): 8.898
TOC Elevation (feet AMSL*): 10.763
Total Depth (feet): 45
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
-3							
-1						Ground Surface	
1					●	***Grey to Brown FILL (FL)*** gravel and medium-grained sand	
3	1	0		15%	●		
5					●		
7	2	0		100%	▨	***Grey CLAY (OH) - MUCK*** organic; saturated	
9					▨		
11					▨		
13	3	0		100%	▨		
15					▨		
17					▨		



Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: HSA ☐ Geoprobe ☐ Rotosonic ☑

ID(inches): 2

** AMSL= Above mean sea level*

Boring Log: W-18B

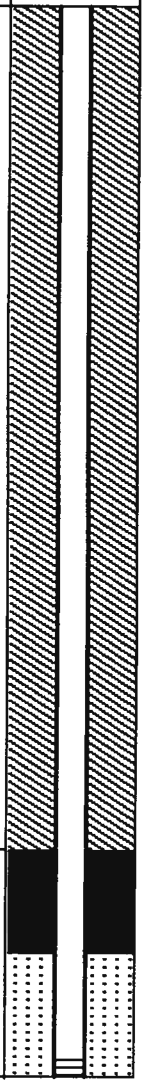
Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 14, 2003

Surface Elevation (feet AMSL*): 8.898
TOC Elevation (feet AMSL*): 10.763
Total Depth (feet): 45
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile	
Depth	Sample Interval	PID/OVM (ppm)	Blow Count	% Recovery	Lithology	Description
19	4	0		50%	▨	
21 23	5	0		50%	▨	
25 27 29	6	0		100%	▨	
31 33	7	0		100%	▨ ░	***Grey SAND (SW/SP)*** fine- to medium-grained, well-graded to well sorted sand with some clay interbeds up to 2 inches thick; saturated
35 37					░	

Well Construction



Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: HSA ☐ Geoprobe ☐ Rotosonic ☑
ID(inches): 2

** AMSL= Above mean sea level*

Boring Log: W-18B

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: May 14, 2003

Surface Elevation (feet AMSL*): 8.898
TOC Elevation (feet AMSL*): 10.763
Total Depth (feet): 45
Borehole Diameter (inches): 6

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	Sample Interval	PID/OVM (ppm)	Blow Count	% Recovery	Lithology	Description	Well Construction
39	8	0			░		
41					░		
43	9	0			▨	*Greenish Grey Silty CLAY (CL) - HAWTHORNE* dense clayey silt; moist	
45							
47							
49							
51							
53							
55							
57							

Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: R. Buckenberge

Method: HSA ☐ Geoprobe ☐ Rotosonic ☑
ID(inches): 2

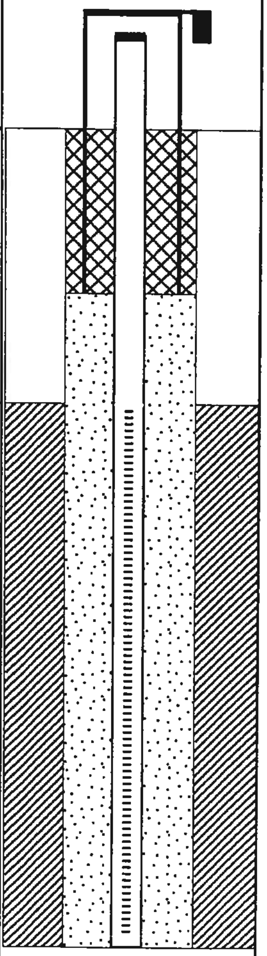
** AMSL= Above mean sea level*

Boring Log:* *MW-21A

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: October 5, 2004

Surface Elevation (feet AMSL*): 12.5
TOC Elevation (feet AMSL*): 12.50
Total Depth (feet): 15
Borehole Diameter (inches): 8.25

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
-3 -1						Ground Surface	
1 3	1	—	—	0		***No Recovery***	
5 7 9 11 13	2	—	—	0	▨	***Silty Clay (CL)*** Loose silty clay material; saturated.	
15 17							

Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: --------------------

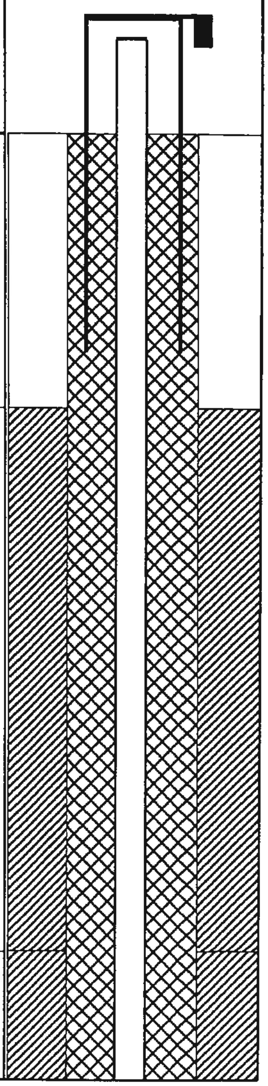
Method: HSA ☐ Geoprobe ☐ Rotosonic ☑
ID(inches): 2

** AMSL= Above mean sea level*

Boring Log:* *MW-21B

Project:	Kerr-McGee	**Surface Elevation (feet AMSL*):**	12.5
Project No.:	558908	**TOC Elevation (feet AMSL*):**	12.45
Location:	Savannah, GA	**Total Depth (feet):**	55
Completion Date:	October 5, 2004	**Borehole Diameter (inches):**	8.25

ENVIRONMENTAL STRATEGIES

Sample Data					**Subsurface Profile**		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
-3 -1						Ground Surface	
1 3	1	---	---	0		***No Recovery***	
5 7 9 11 13	2	---	---	0	▨	***Silty Clay (CL)*** Loose silty clay material; saturated.	
15 17					▨	***Gray Silty Clay (CL)*** Saturated gray silty clay.	

Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: Ken Gobbl

Method: **HSA** ☐ **Geoprobe** ☐ **Rotosonic** ☑
ID(inches): 2

** AMSL= Above mean sea level*

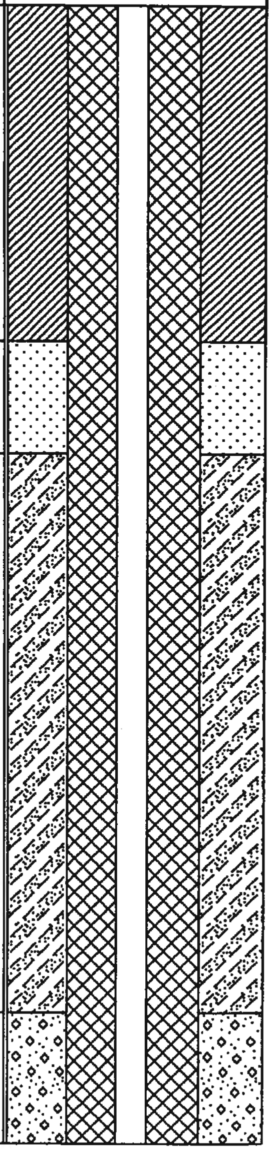
Boring Log: MW-21B

Project: Kerr-McGee	**Surface Elevation (feet AMSL*):** 12.5
Project No.: 558908	**TOC Elevation (feet AMSL*):** 12.45
Location: Savannah, GA	**Total Depth (feet):** 55
Completion Date: October 5, 2004	**Borehole Diameter (inches):** 8.25

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile	
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**
19 21	3	0	---	100		
23						***Gray Sand (SW)*** Saturated fine gray sand.
25 27 29 31 33	4	0	---	100		***Gray Silty Clay (CL)*** Saturated gray silty clay with interbedded gray fine sand.
35 37						***Gray Sand (SW)*** Staturated gray fine to coarse sand.

Well Construction



Geologist(s): DRL	**Method:**	**HSA** ☐ **ID(inches):** 2
Subcontractor: Boart-Longyear		**Geoprobe** ☐ **Rotosonic** ☑
Driller/ Operator: Ken Gobbl		

** AMSL= Above mean sea level*

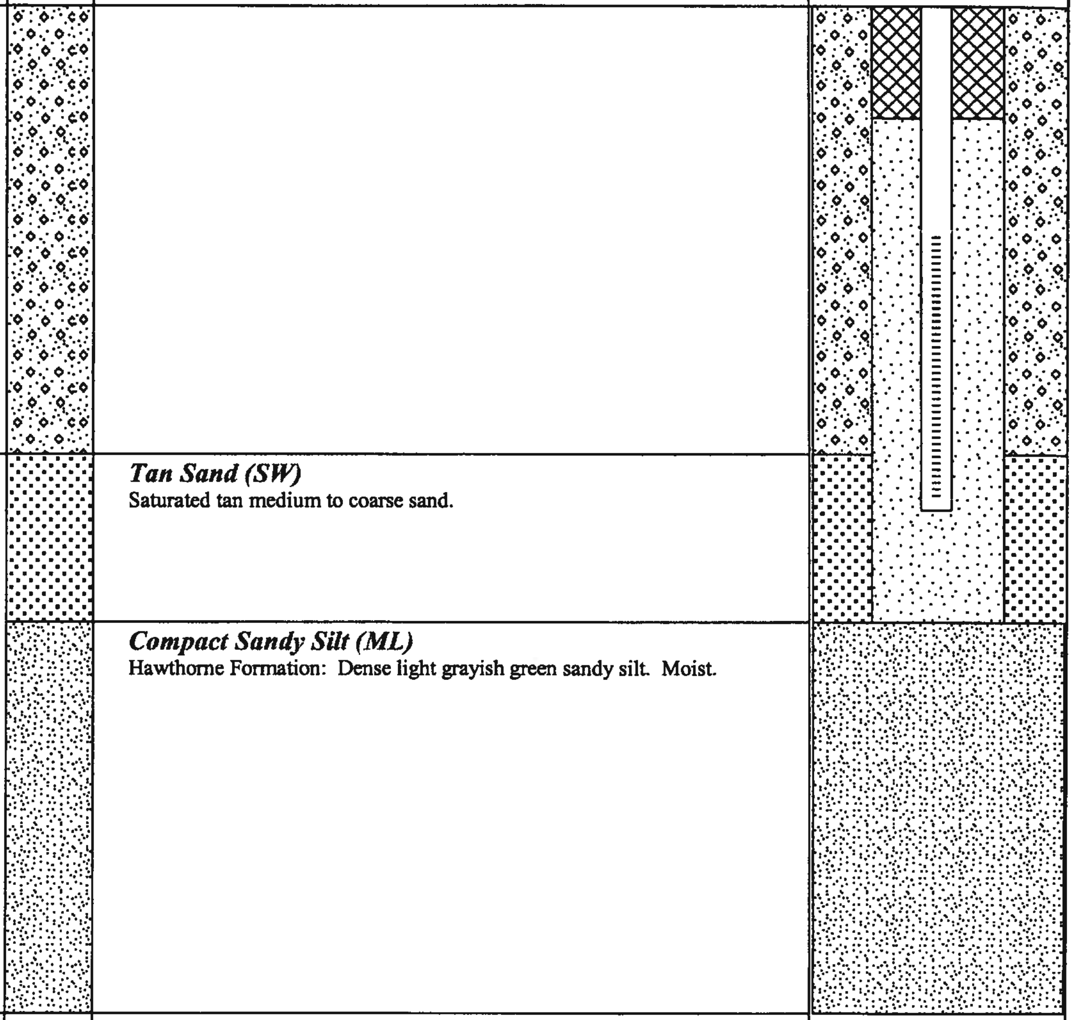
Boring Log:* *MW-21B

Project: Kerr-McGee
Project No.: 558908
Location: Savannah, GA
Completion Date: October 5, 2004

Surface Elevation (feet AMSL*): 12.5
TOC Elevation (feet AMSL*): 12.45
Total Depth (feet): 55
Borehole Diameter (inches): 8.25

ENVIRONMENTAL STRATEGIES

Sample Data					Subsurface Profile		
Depth	**Sample Interval**	**PID/OVM (ppm)**	**Blow Count**	**% Recovery**	**Lithology**	**Description**	**Well Construction**
39 41 43	5	0	—	100			
45 47						***Tan Sand (SW)*** Saturated tan medium to coarse sand.	
49 51 53	6	0	—	100		***Compact Sandy Silt (ML)*** Hawthorne Formation: Dense light grayish green sandy silt. Moist.	
55 57							



Geologist(s): DRL
Subcontractor: Boart-Longyear
Driller/ Operator: Ken Gobbl

Method: **HSA** ☐ **Geoprobe** ☐ **Rotosonic** ☑
ID(inches): 2

** AMSL= Above mean sea level*

FIGURE 5

wner American Cyanamid Company
ocation Weak Acid Pond
North side, east hole
riller Paul N. Clawson
Well Use Monitoring
WELL No. M-2

Screen 2in.x6ft. Slot .020
Set From 38 To 44
Well Produces GPM at
Pump
Water table
Collar Elevation 14.66 ft.(MLW)

Depth rom	To	Lithology	Mud Loss	Remarks
0	3½	Fill - coarse sand w/minor clay.		
3½	12	Coarse sand w/beds of soft clay up to 8" thick. Tough clay bed 9-3/4-10½ft.		
12	33	Soft gray marsh muck, few thin beds coarse sand. Much plant material.		
33	37½	Tough gray clay.		
7½	45 TD	Coarse sand.		
		Set 6 ft. screen 38 - 44		

Figure 3
Well Construction Diagram