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REVISED FIELD SAMPLING PLAN FOR OU3 SUPPLEMENTAL REMEDIAL INVESTIGATION

Shieldalloy Metallurgical Corporation Superfund Site Operable Unit 3 Perchlorates

Prepared for

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Newfield, New Jersey 08344

Prepared by

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Project JR0241

August 2020

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TABLE OF CONTENTS

1. INTRODUCTION 1
   1.1 Scope 1
   1.2 Site Location and History 1
   1.3 Environmental Investigations and Remediation 2
   1.4 Perchlorate in the Regional Environment 3
   1.5 Site Geologic, Hydrogeologic, and Hydrologic Setting 3
      1.5.1 Geology 3
      1.5.2 Hydrogeology 4
   1.6 Summary of Risk Assessments 4

2. PROJECT SCOPE 6
   2.1 Field Sampling Tasks 6
   2.2 Analytical Laboratory Services 6
   2.3 Data Validation and Usability 6

3. GROUNDWATER INVESTIGATION 7
   3.1 Phase 1 7
   3.2 Phase 2 8
   3.3 Purging and Sampling Procedures 9
   3.4 Quality Control Samples 10
   3.5 Calibration 11
   3.6 Decontamination 11
   3.7 Investigation Derived Waste 12

4. PROPOSED ADDITIONAL GROUNDWATER MONITORING 13
   4.1 Scope of Work 13
   4.2 Monitoring Schedule 13

5. DOCUMENTATION, SAMPLE PACKING, AND SHIPPING 14
   5.1 Field Log Book 14
   5.2 Sample Nomenclature 14
   5.3 Sample Packing and Shipping 15
      5.3.1 Sample Custody 15
      5.3.2 Chain of Custody 15
      5.3.3 Sample Packing and Shipping 16
   5.4 Laboratory Deliverables 16

6. HEALTH AND SAFETY PLAN 17

7. REPORTING 18

8. SCHEDULE 19

9. REFERENCES 20

LIST OF FIGURES

Figure 1: Site Location

Figure 2: Areas of Historic Perchlorate Use

Figure 3: Proposed Groundwater Sampling Locations

LIST OF APPENDICES

Appendix A: Quality Assurance Project Plan

Appendix B: Standard Operating Procedures

Appendix C: Environmental Isotope Geochemistry Laboratory CSIA Sampling Protocol

Appendix D: Health and Safety Plan

LIST OF ATTACHMENTS

Attachment A: Previous Perchlorate Analytical Results

Attachment B: Relevant Boring Logs, Vertical Profiling Logs, and Well Construction Diagrams

ACRONYMS AND ABBREVIATIONS

CERCLA	Comprehensive Environmental Response, Compensation and Liability Act
CPS	calcium polysulfide
COC	contaminant of concern
CSIA	Compound Specific Isotope Analysis
DSRA	Development and Screening of Response Alternatives
EISB	Enhanced In Situ Bioremediation
EVO	emulsified vegetable oil
FSPM	Field Sampling Procedures Manual
gpm	gallons per minute
GWQS	New Jersey Groundwater Quality Standard
HASP	Health and Safety Plan
HAZWOPER	Hazardous Waste Operations and Emergency Response
HHRA	Human Health Risk Assessment
ID	identifier
IHAL	Interim Health Advisory Level
MNA	monitored natural attenuation
NJDEP	New Jersey Department of Environmental Protection
ORP	Oxidation-reduction potential
OSHA	Occupational Safety and Health Administration
OU	Operable Unit
QAPP	Quality Assurance Project Plan
RSL	Regional Screening Level
SLERA	Screening-Level Ecological Risk Assessment
SMC	Shieldalloy Metallurgical Corporation
SOP	Standard Operating Procedure
SOW	scope of work
TCE	trichloroethene
TRC	TRC Environmental Corporation
USEPA	United States Environmental Protection Agency

1. INTRODUCTION

On behalf of Shieldalloy Metallurgical Corporation (SMC), Geosyntec Consultants, Inc. has prepared this Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation (Revised FSP OU3 SRI) to address Operable Unit (OU) 3 Perchlorates at the Shieldalloy Corporation Superfund Site in Newfield, New Jersey. OU3 is defined by United States Environmental Protection Agency (USEPA) as perchlorate contamination in soil, groundwater, and surface water and sediment in Site-associated bodies of water. This Revised FSP OU3 SRI was prepared in accordance with USEPA's Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA (USEPA, 1988).

An FSP OU3 SRI was initially submitted to USEPA in December 2019, and approved by USEPA. Subsequently, Shieldalloy proposed an alternative approach to the investigation of OU3, and USEPA concurred. This Revised FSP OU3 SRI describes the alternative approach.

1.1 Scope

Attachment A includes previously collected data that shows perchlorate concentrations in Site soil, surface water and sediment are below respective USEPA Residential Regional Screening Levels (RSLs). Consequently, the Revised FSP OU3 SRI focuses further investigation on perchlorate contamination of groundwater. The most recent groundwater sampling for perchlorate at the Site was in 2011. Though the perchlorate plume was well-defined at that time, more current groundwater sampling is needed to assess whether conditions have changed.

The aim of this Revised FSP OU3 SRI is to:

- Investigate the current extent of the perchlorate plume;
- Assess the geochemical characteristics of the aquifer and the potential influence of these characteristics on potential remedies for perchlorate, including monitored natural attenuation (MNA);
- Evaluate potential background sources of perchlorate; and
- Provide current data that will inform later remedy selection documents, including the Development and Screening of Response Alternatives (DSRA) and Feasibility Study.

1.2 Site Location and History

The Site is comprised of 67.7 acres previously devoted to manufacturing (Main Facility) and 19.8 acres of farmland (Farm Parcel) located about 2,000 feet apart. The Site is mainly located in Newfield, Gloucester County, New Jersey, though portions fall within Vineland, Cumberland County, New Jersey municipal bounds. The Site address is 35 South West Boulevard, Newfield. Figure 1 shows the Site location.

Specialty glass manufacturing began at the Main Facility in 1924. SMC purchased the facility in the early 1950s and, from 1955 to approximately 2007, manufactured items such as specialty steel and super alloy additives, primary aluminum master alloys, metal carbides, powdered

metals and optical surfacing products. Current and historical use of the Farm Parcel remains agricultural.

According to information provided by SMC staff generally familiar with past operational practices, solid potassium perchlorate was used as an oxidizer in the on-Site furnace to increase temperature and enhance furnace performance. The furnace was located within the footprint of former Building D102(A), attached to but isolated from Building D112. Both buildings have since been demolished. Building D102(A) was characterized by an earthen floor (although the area surrounding the building is currently and was historically paved). According to historical purchase order records, SMC purchased approximately 400,000 pounds of potassium perchlorate from 1974 to 1992 for this operational activity. Solid potassium perchlorate was typically packaged and shipped to the Site in 110-, 250-, and 350-pound, plastic-lined steel drums. Prior to being used in the furnace, this product was reportedly stored on Site in a former small metal outbuilding (referred to as the Former Chemical Storage Building), east of former Building D102(A) and near the unpaved road forming the northwest boundary of the storage yard slag piles. This Former Chemical Storage Building was characterized by a concrete interior floor and berm around the building's perimeter. Based on this reported information, the storage and usage of perchlorate on Site were limited to these areas, which are identified in Figure 2. Since perchlorate was completely destroyed in the heating process by reacting with aluminum to form chlorides, there was no general release from this process. Only incidentally spilled material or small amounts of incompletely reacted material were released into the environment. One possible disposition for incompletely reacted/residual perchlorate was release to a former lagoon area, also shown in Figure 2 (TRC, 2016).

1.3 Environmental Investigations and Remediation

The Site has an extensive history of soil, groundwater, sediment and surface water investigation. Environmental investigations at SMC began in 1972 to determine whether there was a relationship between the Site's operations and elevated concentrations of metals in the municipal water supply. Remedial activities that may be relevant to perchlorate investigation and remediation are summarized below (TRC, 2008) (USEPA, 2015):

- SMC installed an 80 gallons per minute (gpm) groundwater pump and treat system in 1979 to remediate chromium and trichloroethene (TCE). The groundwater was treated using ion exchange.
- SMC installed additional wells and increased extraction to 400 gpm to control off-Site migration of hexavalent chromium in 1988 and 1989.
- SMC expanded the treatment system to include an air stripper to address TCE.
- SMC switched from ion exchange to electrochemical precipitation in 1991 to address chromium concentrations in the extracted groundwater.
- SMC characterized, treated and closed nine wastewater treatment lagoons from 1994 to 1997.
- Investigation of plume geometry of various contaminants of concern (COCs) through vertical profiling and monitoring well installation was completed from 2002 to 2011.

- In situ remediation treatability studies began in 2010 after finding the current treatment systems were no longer efficiently treating Site COCs (concentration reduction had become asymptotic). Calcium polysulfide (CPS) was identified as an effective reagent for treating chromium-impacted groundwater. Emulsified Vegetable Oil (EVO) was found to be an effective electron donor to promote microbial degradation of TCE.
- SMC installed a new ion exchange unit in the groundwater treatment plant in 2011.
- TRC conducted an Ecological Risk Assessment and a Human Health Risk Assessment for OU3 in 2013 and 2014, respectively.

Perchlorate impacts were initially assessed during monitoring events in 2004. Concentrations in soil, surface water and sediment were reported to be below respective USEPA Residential RSLs. Therefore, these media were not further evaluated. Perchlorate concentrations in groundwater were above the New Jersey Class II-A Ground Water Quality Standard (GWQS) of 5 parts per billion (ppb) (TRC, 2014) (NJDEP, 2018). Data obtained for all media are included in Attachment A to this document.

Periodic groundwater sampling was conducted until 2011, when the perchlorate plume was sufficiently defined to the USEPA Interim Health Advisory Level (IHAL) of 15 ppb. Isopleths developed from the 2011 data are provided in Attachment B and show perchlorate present at concentrations above the GWQS in the shallow, intermediate and deep aquifer zones, with the plume deepening and migrating in a southwesterly direction under the influence of advective groundwater transport and a downward hydraulic gradient (TRC, 2016).

1.4 Perchlorate in the Regional Environment

Moderate perchlorate concentrations in the deep aquifer zone in wells that are located upgradient of the Site's potential perchlorate source areas suggest that there may be a regional perchlorate contamination issue unrelated to Site activities (data provided in Attachment A). The regional presence of perchlorate may have resulted from the extensive agricultural land use within the area and the potential use of Chilean-nitrate fertilizers (of which perchlorate is a component) on the area farms. The documentation of the presence of perchlorate in lettuce crops in Newfield and Bridgeton and spinach crops in Vineland (U.S. Food and Drug Administration, 2005) and the historical use of irrigation wells in the area provide additional evidence of the potential for a regional groundwater perchlorate issue. In 2009, drinking water quality testing conducted by the City of Vineland (which obtains its drinking water from groundwater) included perchlorate as an analyte under the Unregulated Contaminant Monitoring Rule (City of Vineland, 2009). Perchlorate was reported at concentrations ranging from 5.18 to 6 ppb in drinking water supply samples, demonstrating the regional presence of perchlorate in the groundwater (TRC, 2016).

1.5 Site Geologic, Hydrogeologic, and Hydrologic Setting

1.5.1 Geology

Three unconsolidated sedimentary units underlie the Site. From shallowest to deepest they are:

- The Bridgeton Formation - consists of up to 28 feet of brown sand and is present in the eastern portion of the Site (TRC, 2011);

- The Cohansey Sand – is the primary aquifer of concern and is comprised of coarse sands and little silt in the upper 40 feet, with generally finer sand and some clay and silt lenses in the lower 60 to 80 feet. Discontinuous silt and clay up to 6 feet in thickness is found within the lower section of the formation. The Cohansey Sand is predominantly composed of quartz, and secondary minerals include aluminum oxides and iron-containing minerals (e.g. illite and pyrite) (TRC, 2015); and
- The Kirkwood Formation – the upper portion of this unit consists of a gray silt and clay layer and is generally encountered between 121 and 153 feet below ground surface (ft bgs).

Bedrock has not been encountered in previous Site investigations; it is estimated that the depth to bedrock beneath the Site is approximately 2,000 ft bgs (TRC, 2016).

1.5.2 Hydrogeology

The principal aquifer at the Site and surrounding area is the Cohansey Sand aquifer, which is approximately 130 feet thick. The upper portion of the Kirkwood Formation, consisting of silt and clay, functions as a confining unit by restricting the downward flow of groundwater. Groundwater flow direction in both the upper and lower Cohansey Sand is southwest toward an on-Site stream known as the Hudson Branch. Seasonal fluctuations in water table elevations are on the order of a few feet, and depth to groundwater has been measured at 4 to 27 ft bgs (TRC, 2016) (TRC, 2014).

1.6 Summary of Risk Assessments

In 2014, a Human Health Risk Assessment (HHRA) was conducted for OU3. The assessment rules out soil, surface water and sediment as posing a risk to human health. It reported that the following receptors were at risk of unacceptable perchlorate exposure through ingestion of groundwater, according to USEPA guidance:

- Future child resident exposed to on-Site shallow groundwater;
- Future adult and child resident exposed to off-Site deep groundwater;
- Future child resident exposed to Farm Parcel intermediate groundwater; and
- Future adult and child resident exposed to Farm Parcel deep groundwater.

Since the time the HHRA was completed, New Jersey has adopted a GWQS for perchlorate of 5 ppb for Class II-A groundwater. Class II-A groundwater is defined as groundwater that can be used as potable water or converted to potable water through treatment, mixing or other similar technique (NJDEP, 2018).

Additionally, a Screening-Level Ecological Risk Assessment (SLERA) was conducted in 2013. In accordance with USEPA guidance, the study utilized the maximum concentrations of perchlorate detected in Site soil, groundwater, surface water and sediment to conservatively calculate the concentration of perchlorate that various communities of living organisms might be exposed to, as well as the maximum daily dose that might be consumed by multiple indicator

species. The study concluded that even the highest perchlorate concentrations measured on Site are unlikely to pose a risk to terrestrial or aquatic communities (TRC, 2013).

2. PROJECT SCOPE

2.1 Field Sampling Tasks

The scope of work (SOW) for this project includes:

- Advancing soil borings and collecting groundwater samples from the borings to estimate the current distribution of perchlorate in groundwater at and downgradient of the Site
- Installation of permanent monitoring to wells to confirm the perchlorate distribution, allow collection of samples to evaluate natural attenuation processes for perchlorate, and to allow long-term monitoring of perchlorate
- Potentiometric surface evaluation
- Compound specific isotope analysis (CSIA) and Gene-Trac testing

2.2 Analytical Laboratory Services

Analytical laboratory services will be provided by Eurofins Lancaster Laboratories (Eurofins), Laboratory Certification ID # PA011, for perchlorate and biogeochemical parameter analyses. CSIA will be conducted by the University of Delaware. Gene-Trac samples will be preserved and held for analysis by SiREM, a division of Geosyntec Consultants.

2.3 Data Validation and Usability

After the data are received from the laboratory, data validation will occur as described in the UFP Quality Assurance Project Plan (QAPP) Worksheet #36, Appendix A. Stage 2A validation will be performed on 25% of all samples. Where necessary, data qualifiers will be assigned to provide the basis of describing data quality. Validation qualifiers, reason codes, and comments (as warranted) will be added to each EDD and uploaded to the project database. This information will be supplied to the project team via a validation report and to the data manager through updates to the database.

A data usability assessment will be performedperiodically summarizing the overall quality of the data including field data, field QC data, laboratory QC data, and laboratory data. This will further illustrate the limitations of any qualified data that may have resulted during data validation. The data will be evaluated with regard to compliance with the DQOs and measurement quality objectives. Should non-conformance issues be generated from the laboratory, the validation procedure will evaluate the impacts of the nonconformance(s) on the quality and usability of the data set. Data usability will be assessed with respect to the DQOs and the limits specified in the UFP QAPP Worksheet #37, Appendix A.

3. GROUNDWATER INVESTIGATION

Ten soil borings will be advanced at certain of the previous sampling locations and groundwater samples will be collected to determine current perchlorate concentrations (Phase 1). If the results of Phase 1 indicate that perchlorate is present at concentrations above its GWQS and remediation is required, then permanent nested monitoring wells will be installed and sampled (Phase 2). Phase 2 will include groundwater level measurements, field parameter measurements, perchlorate analysis, and biogeochemical analysis, and may also include CSIA and Gene-Trac testing, depending on the results of the initial sampling round. All standard operating procedures related to this groundwater investigation are included for reference in Appendix B and are summarized in the QAPP worksheets #21 and #22 (Appendix A).

3.1 Phase 1

Ten borings will be advanced, as summarized in the following table and shown on Figure 3. The majority of the borings are on the flow path from the Site to the southwest (based on historical water level data).

Boring Location	Depth	Purpose
GWS1	80 feet	Upgradient, to establish perchlorate concentrations in groundwater entering the Site.
GWS2	120 feet	Within former area of highest concentrations on Site.
GWS3	130 feet	At Farm Parcel, downgradient of Site, where pumping wells were operated for OU1.
GWS4	120 feet	At former boring location VP-8, where highest concentrations of perchlorate were detected in the off-Site deep zone.
GWS5	140 feet	At former boring location VP-5, to establish southern (side gradient) boundary of perchlorate.
GWS6	120 feet	At former boring location VP-13A, to establish northern (side gradient) boundary of perchlorate.
GWS7	120 feet	At former boring location VP-2, where elevated levels of perchlorate were observed in intermediate and deep zones.

GWS8	120 feet	Near former boring location VP-10, to delineate downgradient edge of perchlorate.
GWS9	120 feet	On West Forest Grove Road, west of former boring location VP-10, to delineate downgradient edge of perchlorate.
GWS10	110 feet	Near former boring location VP-15A, to delineate downgradient edge of perchlorate.

The aquifer at and downgradient of the Site is underlain by a clay aquitard (TRC, 2011). The borings will not extend into this aquitard; when the clay layer is reached (typically at depths ranging from 110 to 130 feet bgs), drilling will be stopped, and the boring will be considered complete. Therefore, the actual depth of the borings may vary from what is proposed in the table above.

All borings will be drilled by a New Jersey-licensed driller using a MiniSonic drill rig with a 4-inch diameter bit and located in public right of ways. Groundwater samples will be collected every 20 feet beginning at 20 feet bgs. The samples will be collected by the PushAheadTM sampling method; a standard operating procedure (SOP) for this method is provided in Appendix B. When the boring is complete, it will be backfilled in accordance with New Jersey requirements.

Six to seven groundwater samples will be collected at most of the boring locations, for a total of 60 to 70 perchlorate samples during Phase 1. Appropriate quality assurance samples will also be obtained, as described in Section 3.5. All groundwater samples will be analyzed for perchlorate using method SW-846 6850. Analytical results will be compared to the GWQS of 5 ppb.

Note that the samples from the first borings may be analyzed on an expedited turnaround. This will allow the placement of the remaining borings to be adjusted to be most efficient for characterizing the horizontal and vertical extent of the perchlorate. For example, if perchlorate levels in the center of the study area (e.g., at the Farm Parcel) are higher than in the previous data, the downgradient borings may be moved to the southwest to define the downgradient edge of the plume. The analytical data and any proposed changes to the boring locations will be discussed with USEPA before adjusting any boring locations.

3.2 Phase 2

Phase 2 will be implemented if the results of Phase 1 indicate that perchlorate is present at concentrations above its GWQS and remediation is required. Phase 2 will consist of the installation and sampling of well nests. Each well nest will contain three wells, one each in the shallow, intermediate, and deep zones. The exact number and locations of the well nests will be determined following the completion of Phase 1.

The wells will be installed by a New Jersey-licensed driller using a sonic drill rig. The well screens will be 10 feet long. The depths of the screened intervals in each well nest will be

determined based on the Phase 1 results; all screens will be set in each zone at the depths most likely to encounter perchlorate at that location.

Static groundwater level measurements will be collected at all new wells to confirm the potentiometric surface elevation. Measurements will be collected according to SOP 100 (Appendix B). A PID will be used for health and safety purposes to screen the well headspace upon opening each well. All new wells will then be sampled using low flow sampling methodology, as described in Section 3.4. Appropriate quality assurance samples will also be obtained as detailed in the QAPP and Section 3.5. Field parameters, including temperature, pH, specific conductivity, dissolved oxygen (DO), turbidity, and oxidation-reduction potential (ORP) will be monitored while purging at each location.

Samples will be analyzed for perchlorate using method SW-846 6850. In addition, samples at selected new wells will be analyzed for the following parameters to evaluate potential natural attenuation processes for perchlorate:

- Total and dissolved iron;
- Nitrate;
- Sulfate;
- Sulfide;
- Orthophosphate;
- Alkalinity;
- Total organic carbon;
- Total dissolved solids; and
- Dissolved hydrocarbons (methane, ethane, and ethene).

In addition, samples may be collected for CSIA and Gene-Trac testing. The locations for these samples will be selected in conjunction with USEPA. If collected, CSIA samples will preferentially be collected at locations on the perimeter of the perchlorate plume and with perchlorate concentrations of at least 5 ppb.

3.3 Purging and Sampling Procedures

Each permanent monitoring well installed during Phase 2 will be purged and sampled in accordance with SOP 108 (Appendix B) and the USEPA Region 2 low-flow purge protocol. Samples will be analyzed for perchlorate, as well as biogeochemical parameters. A peristaltic pump and dedicated polyethylene tubing will be used at each monitoring well. If the water level draws down to a level below the capibilities of the peristaltic pump, a bladder pump will be used instead. Tubing or pump intake will be placed within the middle of the screened interval to be best situated to capture groundwater flowing into the well from the aquifer.

During purging, field measurements will be recorded every five minutes from a flow-through cell for pH, specific conductance, temperature, dissolved oxygen, oxidation/reduction potential, and turbidity. Depth to water will also be monitored during purging and the discharge rate will be adjusted to limit the drawdown in the depth to water to 1 foot or less.

Water quality indicator parameters will be considered stable when they meet the following criteria for three consecutive readings taken at five-minute intervals:

- water level drawdown <0.3 ft;
- temperature +/- 3%;
- pH +/- 0.1 pH units;
- specific conductance +/- 3%;
- dissolved oxygen +/- 10% for values greater than 0.5 mg/L, if three dissolved oxygen values are less than 0.5 mg/L, consider the values as stabilized;
- turbidity +/- 10% for values greater than 5 NTU, for values less than 5 NTUs, consider the values as stabilized; and
- ORP/eh +/- 10 millivolts.

In the event that field parameters do not stabilize within four hours, purging will be discontinued, and a sample will be collected. Dissolved iron and orthophosphate samples will be field filtered using a 0.45 µ filter as specified in QAPP Worksheet #19 (Appendix A).

At each sampling location, all bottles designated for a particular analysis will be filled sequentially before bottles designated for the next analysis are filled. If a duplicate sample is to be collected at the location, all bottles designated for a particular analysis for both sample designations will be filled sequentially before bottles for another analysis are filled, as described in Section 3.4. Bottleware for dissolved hydrocarbon analysis will be filled before samples of other chemical groups. Groundwater samples will be transferred directly into the appropriate sample containers with preservative, if required, placed on ice in a cooler, and processed for shipment to the laboratory.

CSIA sampling will be conducted as per the Environmental Isotope Geochemistry Laboratory protocol, provided in Appendix C.

3.4 Quality Control Samples

Duplicate and matrix spike/matrix spike duplicate samples will be collected at a rate of 1 per 20 samples for the perchlorate and biogeochemical samples. Duplicate samples will be collected at a rate of 1 per 10 for the CSIA samples. Matrix spike/matrix spike duplicate samples will not be collected for the CSIA and Gene-Trac analyses. Additionally, duplicate samples will not be collected for the Gene-Trac analyses.

Duplicate samples will be collected from wells that are expected to exhibit moderate concentrations of contaminants. When collecting duplicate water samples, bottles with the two different sample identification numbers will alternate in the filling sequence (e.g., a typical filling sequence might be: dissolved hydrocarbons designation GW-2, dissolved hydrocarbons designation DUP-01 (duplicate of GW-2); metals designation GW-2, metals designation DUP-01, (duplicate of GW-2) etc.). Note that bottles for one type of analysis will be filled before

bottles for the next analysis are filled. Bottles for dissolved hydrocarbons will always be filled first.

Equipment blanks and field blanks will be collected for perchlorate and biogeochemical parameters each day sampling is conducted for the parameters being collected on that day. Equipment blanks and field blanks will not be collected for Gene-Trac and CSIA parameters. One equipment blank will be collected at the beginning of each day that sampling is conducted by pouring laboratory supplied deionized water over polyethylene tubing into the designated bottleware. The field blank will be collected by pouring laboratory supplied deionized water directly into the designated bottleware.

Duplicate, matrix spike/matrix spike duplicate, field, and equipment rinsate blanks will be preserved, packaged, and sealed in the manner described for the environmental samples.

A laboratory supplied temperature blank will accompany each cooler throughout the field event.

A laboratory supplied trip blank will accompany dissolved hydrocarbon bottleware during shipment from the lab, transport on Site, and return shipment to the lab.

3.5 Calibration

Calibration of the YSI water quality sonde and turbidimeter will be conducted according to the following SOPs: SOG NJ1 through SOG NJ5 (provided in Appendix B and summarized in Appendix A: QAPP Worksheets #21 and 22). Calibration will be performed in the beginning of the day before purging and sampling, and a calibration check will be performed at the end of each day the equipment is used according to SOP 110, included in Appendix B for reference.

Calibration of the Minirae PID will be conducted according to the QAPP Worksheet #22 (Appendix A). The PID will be calibrated at the beginning of each day.

3.6 Decontamination

All non-dedicated and non-aqueous field sampling equipment that comes into contact with groundwater will be decontaminated according to the below three-step process from the New Jersey Field Sampling Procedures Manual (FSPM). Bladder and Grundfos pumps will be dissassembled prior to decontamination to allow for cleaning of the internal parts.

The field sampling equipment cleaning and decontamination procedures are as follows:

- Laboratory grade glassware detergent and tap water scrub to remove visual contamination
- Generous tap water rinse
- Distilled (ASTM Type II) water rinse

All sampling equipment decontaminated via this procedure will be wrapped in aluminum foil during storage and prior to use. Information concerning decontamination methodology, date, time, and personnel will be recorded in the field logbook.

Decontamination will be carried out over a container and the residual liquid material will be containerized in the same manner as the purge water, described in Section 3.7.

Disposable equipment intended for one-time use will not be decontaminated but will be packaged for appropriate disposal.

3.7 Investigation Derived Waste

Soil cuttings and drilling fluids generated during soil boring advancement and well installation will be containerized in drums, characterized, and disposed of at a licensed off-Site disposal facility. Purge water will be poured back down the well immediately following sample collection and removal of the dedicated tubing.

4. PROPOSED ADDITIONAL GROUNDWATER MONITORING

After Phases 1 and 2 are completed, additional rounds of sampling may be conducted to support the potential selection of MNA as a remedy. Up to 8 quarters of monitoring are proposed, including the initial rounds of sampling described above in Section 3.

The aim of this additional monitoring is to:

- Provide adequate data to validate a remedy for OU3 groundwater, or if necessary, provide additional data for selecting a remedy;
- Monitor the geochemical characteristics of the aquifer and the potential influence of these characteristics on the selected remedy for perchlorate, including MNA; and
- Specify the sampling frequency and analytical parameters.

4.1 Scope of Work

Groundwater will be monitored for up to eight quarters to support the remedy selection. The eight quarters of sampling will include the two rounds of sampling described above in Section 3. The monitoring wells will be chosen based on the results of Phases 1 and 2 and will focus on monitoring wells where perchlorate was detected. Samples in all rounds will be analyzed for perchlorate. Samples in the first and last sampling rounds will also be analyzed for biogeochemical parameters that will support evaluation of MNA and enhanced in-situ bioremediation (EISB) remedial alternatives during the Feasibility Study. Biogeochemical parameters may also be analyzed in additional sampling rounds to collect information on seasonality. Biogeochemical parameters include dissolved and total iron, nitrate, sulfate, sulfide, alkalinity, orthophosphate, total dissolved solids, total organic carbon, and dissolved hydrocarbons (methane, ethane, and ethene). Field measurements of temperature, pH, specific conductivity, DO, turbidity, and ORP will be collected at all locations in each round of sampling. CSIA samples may be collected at wells on the perimeter of the perchlorate plume depending on the results of Phases 1 and 2.

During each sampling event, the depth to water will be measured in each monitoring well prior to purging and sample collection. Water levels will be collected as described in Section 3.2.

Each well will be purged and sampled as described in Section 3.3 and in general accordance with the USEPA Region 2 low flow sampling procedures (1998).

Quality control samples will include field duplicates and matrix spike/matrix spike duplicates at a rate of one per twenty samples. In addition, one field blank and one equipment rinsate blank will be prepared for each day that non-dedicated sampling equipment is decontaminated.

4.2 Monitoring Schedule

The groundwater monitoring schedule will be determined following completion of Phases 1 and 2 described in Section 3 above and after discussion with the USEPA.

5. DOCUMENTATION, SAMPLE PACKING, AND SHIPPING

Complete and accurate documentation is essential to demonstrate that field measurement and sampling procedures are carried out as described in the QAPP. Technical records generated during the groundwater investigation will be in sufficient detail to support decisions made and will be maintained by the field lead. The field logbooks will provide documentation of any deviations from the QAPP, a brief rationale, and any details relevant to the changes in procedure. All documents will be archived at the Geosyntec office or off-Site storage facility and included in reports submitted to USEPA.

5.1 Field Log Book

Field personnel will use permanently bound field logbooks with sequentially numbered pages to record and document field activities. Field personnel will adhere to the following general guidelines for maintaining field documentation:

- Documentation will be completed in permanent ink;
- Entries will be legible;
- Errors will be corrected by crossing out with a single line and then dating and initialing the lineout;
- Any serialized documents will be maintained in the project file and referenced in the Site logbook, and;
- Unused portions of pages will be crossed out, and each page will be signed and dated.

5.2 Sample Nomenclature

All samples collected will be labeled in a clear and precise way for proper identification in the field and for tracking in the laboratory, as described in QAPP Worksheet 27 (Appendix A). The sample identifier (ID) for Phase 1 samples collected during boring advancement will include the boring ID and sample depth. The ID for samples collected from permanent monitoring wells will include the well ID and date of sample collection. At a minimum, the sample labels will contain the following information: project name, sample ID, date and time of collection, sample collector's initials, and method of preservation. Parent samples and quality control samples will use the following formats for sample IDs:

Parent Sample	Boring ID_Sample Depth Well ID_YYYYMMDD	Ex: GWS1_20 SC36D_20190731
Duplicate	DUP-XX	Ex: DUP-01
Matrix Spike	Boring ID_Sample Depth_MS Well ID_ YYYYMMDD_MS	Ex: GWS1_20_MS SC36D_20190731_MS

Matrix Spike Duplicate	Boring ID_Sample Depth_MSD Well ID_ YYYYMMDD_MSD	Ex: GWS1_20_MSD SC36D_20190731_MSD
Equipment Blank	EB_ YYYYMMDD	Ex: EB_20190731
Field Blank	FB_ YYYYMMDD	Ex: FB_20190731
Trip Blank	TB_ YYYYMMDD	Ex: TB_20190731

The sample identification given to duplicate samples will be consecutively numbered blind duplicate IDs, the project name, project number, preservative and date collected will be the only identifying information on the label, the time, well identification and sampler's initials sections of the label will all be left blank.

Duplicate sample example: duplicate for a groundwater sample collected from GWS7 as the second duplicate of the sampling event would be as follows: DUP-02.

5.3 Sample Packing and Shipping

5.3.1 Sample Custody

Field personnel will use sample custody procedures according to SOP 101 (Appendix B) and QAPP Worksheets #26 and 27 (Appendix A) to maintain and document sample integrity during collection, transportation, storage, and analysis. The chain of custody record will be used to document all samples collected and the analyses requested. Field personnel will sign chain of custody records that are initiated in the field and will retain copies of these records.

To ensure that sample custody is maintained and recorded, a sample will be considered to be in custody if one of the following statements applies:

- It is in a person's physical possession or view;
- It is in a secure area with restricted access, or;
- It is placed in a container and secured with an official seal so that the sample cannot be reached without breaking the seal.

5.3.2 Chain of Custody

A laboratory supplied chain of custody form will be maintained for all samples throughout the field event as described in QAPP Worksheets #26 and 27 (Appendix A). Field personnel will sign chain of custody records that are initiated in the field and will retain copies of these records and applicable air bills.

To ensure that sample custody is maintained and recorded, a sample will be considered to be in custody if one of the following statements applies:

- It is in a person's physical possession or view;
- It is in a secure area with restricted access, or;

It is placed in a container and secured with an official seal so that the sample cannot be reached without breaking the seal.

5.3.3 Sample Packing and Shipping

Samples will be packed and shipped in accordance with SOP 101 (Appendix B) and QAPP Worksheets #26 and 27 (Appendix A). Samples will be stored in insulated coolers containing wet ice. All perchlorate and biogeochemical samples will be shipped via the laboratory courier service. Gene-trac samples will be shipped via Fed-ex to Sirem Laboratories. CSIA samples will be hand delivered to Environmental Isotope Geochemistry Laboratory: University of Delaware, by a Geosyntec staff member. Chain of custody forms will accompany the samples throughout shipment as described above.

5.4 Laboratory Deliverables

Data generated during laboratory analysis will follow the specifications described in QAPP Worksheet 29 (Appendix A).

6. HEALTH AND SAFETY PLAN

A Site-Specific Health and Safety Plan (HASP) is included as Appendix D. Geosyntec field personnel will have 40-hour Occupational Safety and Health Administration (OSHA) Hazardous Waste Operations and Emergency Response (HAZWOPER) Training and will be current with OSHA HAZWOPER refresher training and medical monitoring. In addition, field personnel will participate in a medical monitoring program.

7. REPORTING

When Phase 1 is completed, a results memorandum will be prepared. The memorandum will present a summary of the field work (including boring logs), tabulated results of the groundwater analyses, and figures (maps and cross sections) showing the groundwater results. A proposal to install permanent monitoring wells (Phase 2) will be included if justified based on the data.

If permanent monitoring wells are needed, then following the installation of permanent monitoring wells, sampling, and analysis, data will be compiled in a Groundwater Summary Memorandum. Electronic data deliverables will be submitted as specified in the QAPP. Following concurrence from USEPA, a DSRA and Feasibility Study will be produced to evaluate remedial options for the Site.

8. SCHEDULE

Phase 1 will be scheduled to occur approximately one month following USEPA and New Jersey Department of Environmental Protection (NJDEP) approval of the Revised FSP OU3 SRI, HASP, and QAPP. The initial sampling round is anticipated to take three to four weeks to complete, and analytical results are expected to be received approximately one month following sampling. The below table outlines the expected completion dates.

Task	Expected Date of Completion
Submittal of the revised project planning documents (Revised FSP OU3 SRI, Revised QAPP, and Revised HASP) to USEPA	August 2020
Address USEPA comments and finalize project planning documents	September 2020
Phase 1 field event	October 2020
Submission of Results Memorandum to USEPA	January 2021
Address USEPA comments and finalize Results Memorandum; implement Phase 2 if justified	April 2021
Submit DSRA to USEPA	September 2021
Address USEPA comments and finalize DSRA	November 2021
Submit Feasibility Study Report to USEPA	March 2022
Presentation on Feasibility Study Report to USEPA	April 2022

9. REFERENCES

NJDEP. 2018. *Ground Water Quality Standards.*

TRC. 2008. *Draft Final Perchlorate Remedial Investigation Work Plan.*

TRC. 2011. *OU1 Supplemental Remedial Investigation Report.*

TRC. 2013. *Final OU3 Screening Level Ecological Risk Assessment.*

TRC. 2014. *Draft Final OU3 Human Health Risk Assessment.*

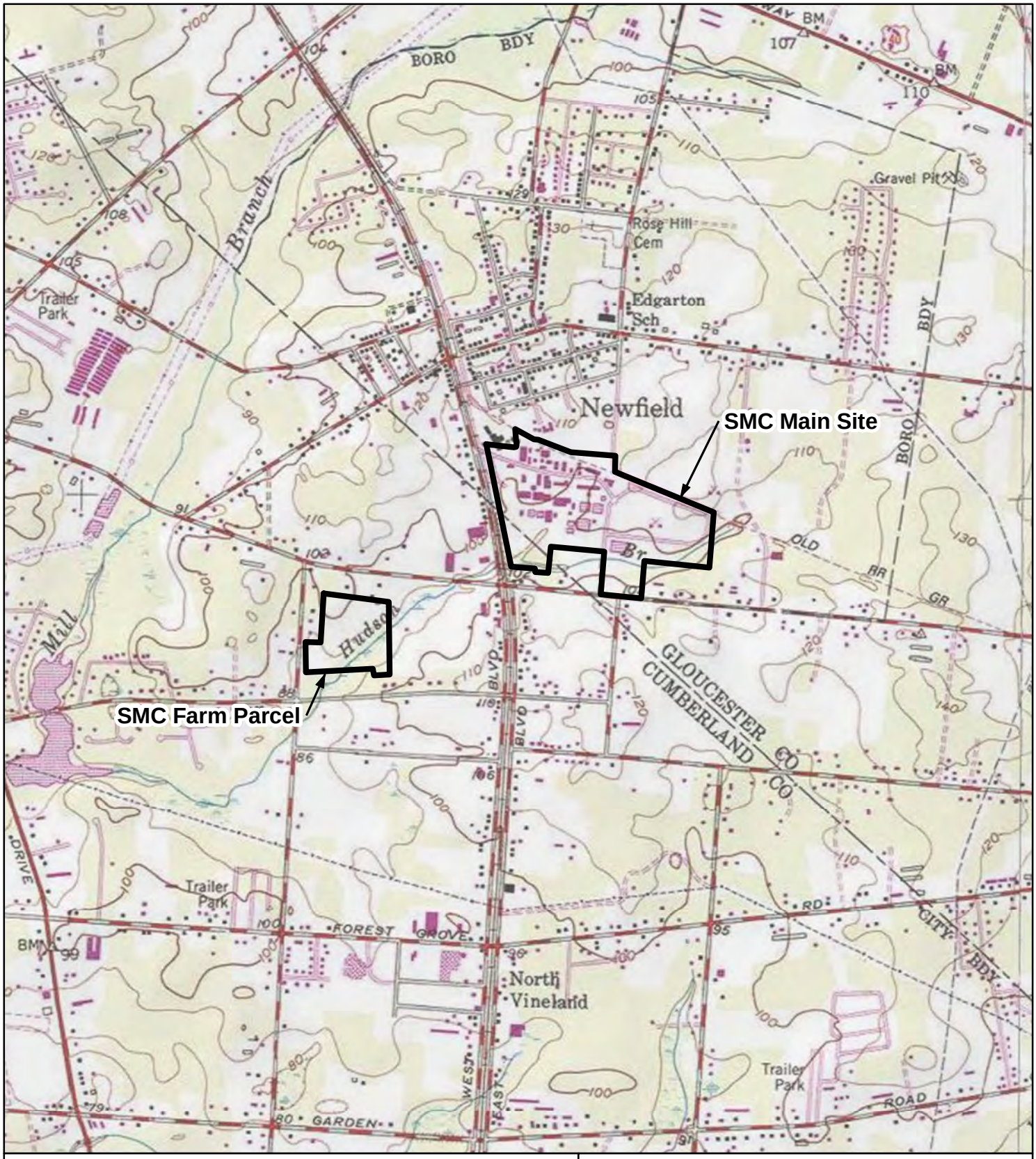
TRC. 2015. *Final Draft OU1 Feasibility Study*.

TRC. 2016. *Remedial Investigation Report.*

USEPA. 1988. *Guidance for Conducting Remedial Investigations and Feasibility Studies Under CERCLA.*

USEPA. 2015. *Record of Decision Amendment. Operable Unit #1 ShieldAlloy Metallurgical Corporation, Newfield, Gloucester County, New Jersey.*

FIGURES



Legend

Site Property Boundary

N

Notes
Base Map: USGS Topographic Map

0 1,680 Feet

Site Location

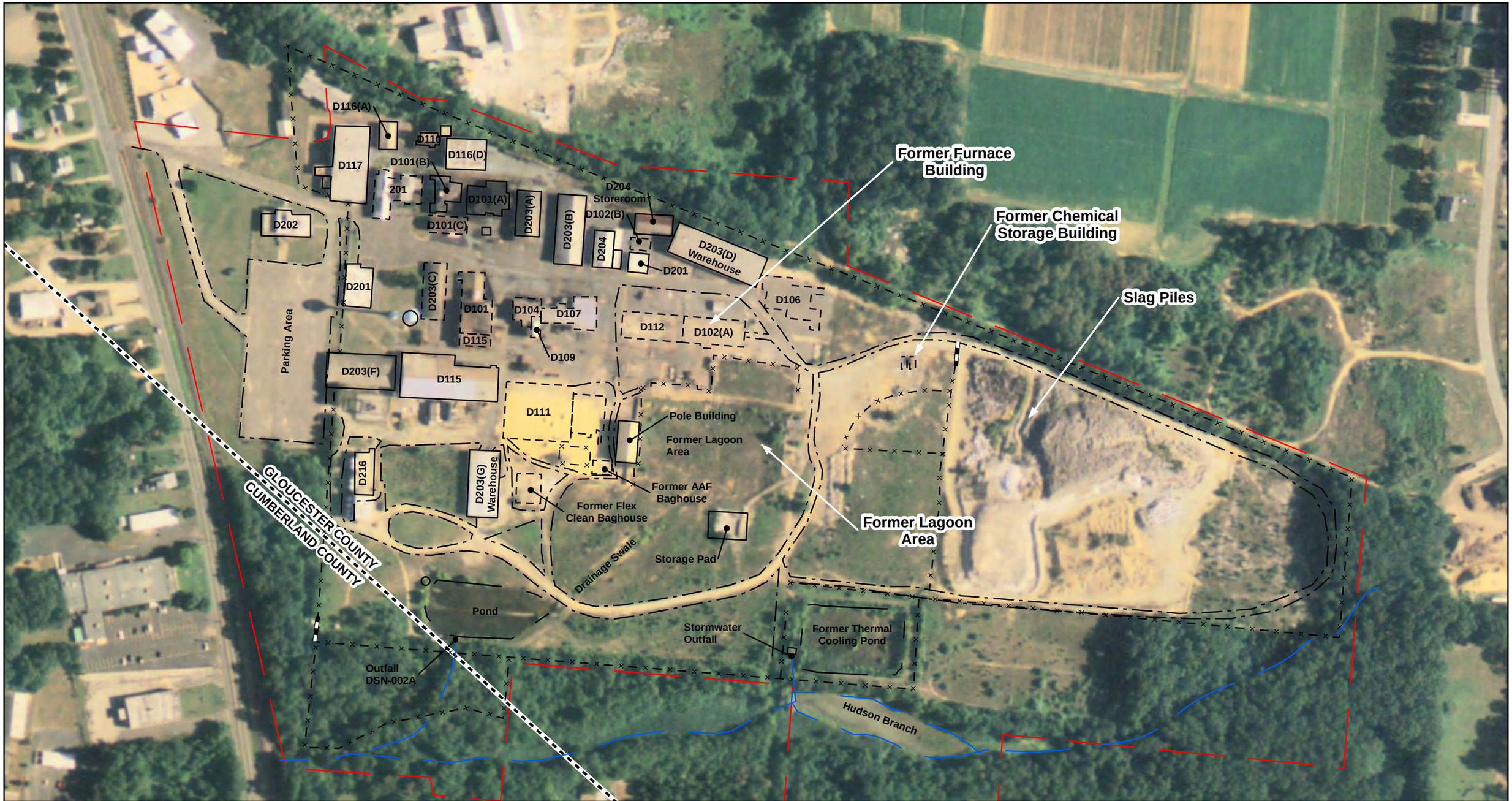
Shieldalloy Metallurgical Corporation
Newfield, New Jersey

Geosyntec consultants

Blue Bell, PA | May 2019

Figure 1

P:\GIS\GISprojects\JR0241 - Sheildalloy\Fig 1 Site Location Map.mxd 1/22/2019 11:22:11 AM



Legend

- Site Property Boundary
- Current Building
- Demolished Building
- Pond
- Road
- Fence Line
- Stream
- Gate

Notes:
The information in this figure is based on TRC Figure 2 from the 2012 OU3 Draft Final Conceptual Site Model and Memorandum of Exposure Scenarios and Assumptions.

N

0 280 Feet

Areas of Historic Perchlorate Use

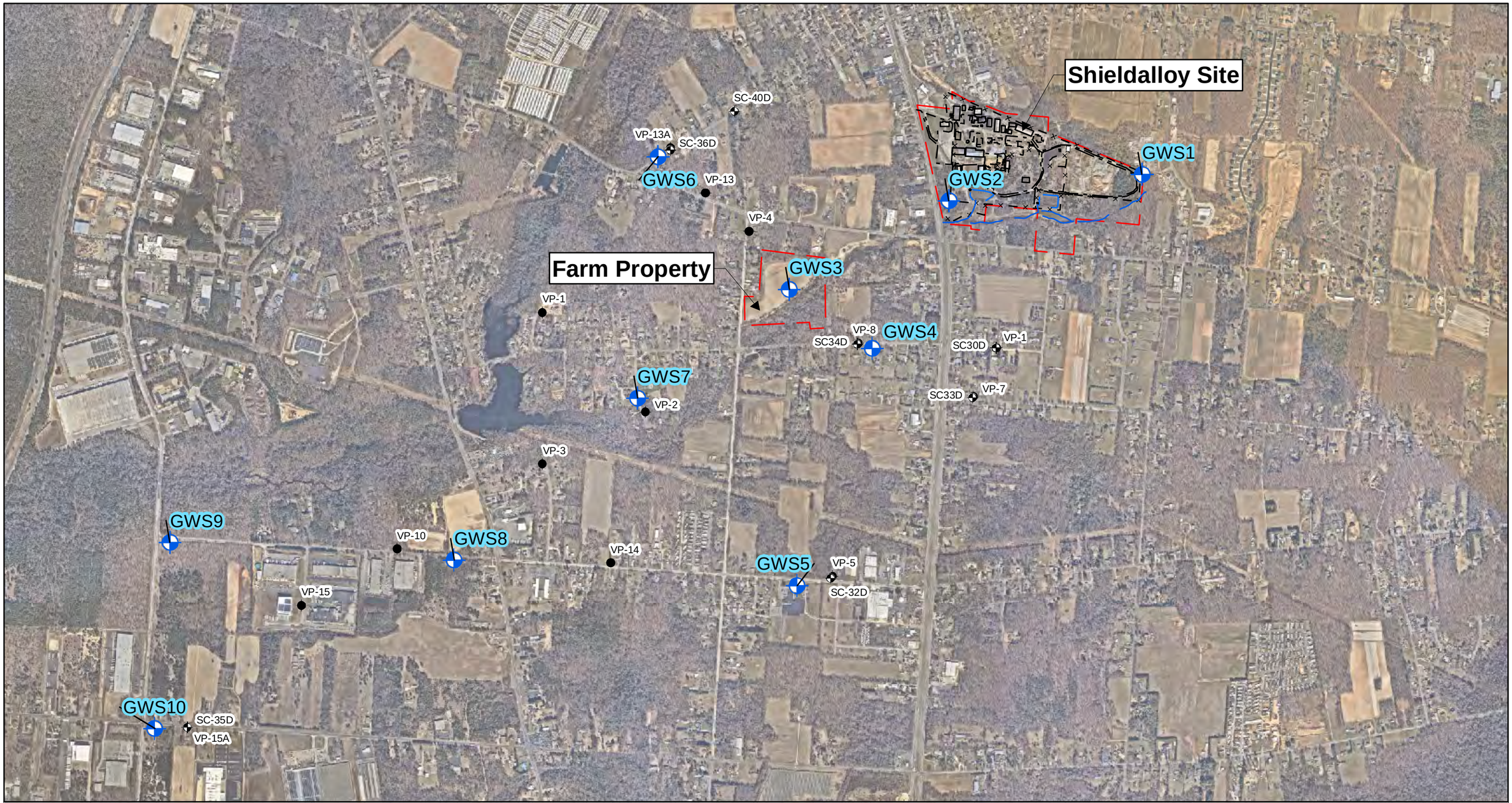
Sheildalloy Metallurgical Corporation
Newfield, New Jersey

Geosyntec consultants

Blue Bell, PA | May 2019

Figure 2

P:\GIS\GISprojects\JR0241 - Sheildalloy\Projects\Areas_of_Hist_Perchlorate_Use.mxd 4/16/2019 1:40:15 PM



Legend

Historical Sampling Locations

- Monitoring Well
- Off Site Vertical Profiling Location

Basemap Features

- Water Feature
- Road
- Gate
- Fence Line
- Site Property Boundary
- Current Building
- Demolished Building
- Fence Line
- Pond

- Proposed Groundwater Sample Location

Notes:
1. The information in this figure is based on TRC Figure 2-3 from the 2011 OU3 Perchlorate Site Characterization Summary Report.
2. Imagery Source: Nearmap, captured on March 9, 2020.

N

0 1,200 Feet

Proposed Groundwater Sampling Locations

Shieldalloy Metallurgical Corporation
Newfield, New Jersey

Geosyntec consultants

Blue Bell, PA | July 2020

Figure 3

P:\GIS\GISprojects\JR0241 - Sheildalloy\Projects\2020\Proposed_GW_Sampling_Locations_20200720.mxd 7/22/2020 12:05:27 PM

APPENDIX A
Quality Assurance Project Plan

TABLE OF CONTENTS

QAPP WORKSHEET #1: TITLE AND APPROVAL PAGE 1

QAPP WORKSHEET #3: DISTRIBUTION LIST 2

QAPP WORKSHEET #4: PROJECT PERSONNEL SIGN-OFF SHEET 3

QAPP WORKSHEET #5: PROJECT ORGANIZATIONAL CHART 5

QAPP WORKSHEET #6: COMMUNICATION PATHWAYS 6

QAPP WORKSHEET #7: PERSONNEL RESPONSIBILITIES AND QUALIFICATIONS 9

QAPP WORKSHEET #8: SPECIALIZED PERSONNEL TRAINING REQUIREMENTS TABLE 10

QAAP WORKSHEET #9: PROJECT PLANNING SESSION SUMMARY 11

QAPP WORKSHEET #10: CONCEPTUAL SITE MODEL 12

QAPP WORKSHEET #11: PROJECT/DATA QUALITY OBJECTIVES 13

QAPP WORKSHEET #12: MEASUREMENT PERFORMANCE CRITERIA 16

QAPP WORKSHEET #14: SUMMARY OF PROJECT TASKS 26

QAPP WORKSHEET #15: PROJECT ACTION LIMITS AND LABORATORY-SPECIFIC DETECTION/QUANTITATION LIMITS 29

QAPP WORKSHEET #15: PROJECT ACTION LIMITS AND LABORATORY-SPECIFIC DETECTION/QUANTITATION LIMITS 30

QAPP WORKSHEET #16: PROJECT TASKS AND SCHEDULE**ERROR! BOOKMARK NOT DEFINED.**

QAPP WORKSHEET #17: SAMPLING DESIGN AND RATIONALE 31

QAPP WORKSHEET #18: SAMPLING LOCATIONS AND METHODS 34

QAPP WORKSHEET #19: ANALYTICAL SOP REQUIREMENTS TABLE 35

QAPP WORKSHEET #19: ANALYTICAL SOP REQUIREMENTS TABLE (CONTINUED)36

QAPP WORKSHEET #20: FIELD QC SUMMARY 37

QAPP WORKSHEET #21: FIELD SOPS 40

QAPP WORKSHEET #22: FIELD EQUIPMENT CALIBRATION, MAINTENANCE, TESTING, AND INSPECTION 42

QAPP WORKSHEET #23: ANALYTICAL SOPS 45

QAPP WORKSHEET #24: ANALYTICAL INSTRUMENT CALIBRATION 48

QAPP WORKSHEET #25: ANALYTICAL INSTRUMENT AND EQUIPMENT MAINTENANCE, TESTING, AND INSPECTION 55

QAPP WORKSHEET #26: SAMPLE HANDLING, CUSTODY, AND DISPOSAL 58

QAPP WORKSHEET #27: SAMPLE CUSTODY REQUIREMENTS 60

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION 63

QAPP WORKSHEET #29: PROJECT DOCUMENTS AND RECORDS 80

QAPP WORKSHEET #30: ANALYTICAL SERVICES 83

QAPP WORKSHEET #31: PLANNED PROJECT ASSESSMENTS 85

QAPP WORKSHEET #32: ASSESSMENT FINDINGS AND CORRECTIVE ACTION RESPONSES 86

QAPP WORKSHEET #33: QA MANAGEMENT REPORTS TABLE 90

QAPP WORKSHEET #34: DATA VERIFICATION AND VALIDATION INPUTS 92

QAPP WORKSHEET #35: DATA VERIFICATION PROCEDURES 96

QAPP WORKSHEET #36: DATA VALIDATION PROCEDURES 100

QAPP WORKSHEET #37: DATA USABILITY ASSESSMENT 102

Geosyntec consultants

QAPP WORKSHEET #1: TITLE AND APPROVAL PAGE

QUALITY ASSURANCE PROJECT PLAN

Shieldalloy Metallurgical Corporation Superfund Site
Operable Unit 3
Perchlorates

Prepared by:

Geosyntec consultants

engineers | scientists | innovators

1750 American Boulevard
Suite 200
Pennington, New Jersey 08534
(609) 895-1400

Review Signatures: _____

John Persico, P.G. / Date: _____
Project Director– Geosyntec

_____
Seth Kellogg / Date: _____
Project Manager – Geosyntec

_____
Livia Capaldi / Date: _____
Quality Assurance Manager – Geosyntec

Approval Signatures: _____

Remedial Project Manager – USEPA Region 2

QAPP WORKSHEET #3: DISTRIBUTION LIST

QAPP Recipients	Title	Organization	Telephone Number	E-mail Address
John Persico	Project Director	Geosyntec	(609) 895-1400	JPersico@geosyntec.com
John Hunt	Director of Environmental Projects	Shieldalloy	(484) 582-3519	jhunt@amg-nv.com
Sherrel Henry	Remediation Project Manager	EPA	212-637-4273	henry.sherrel@epa.gov
Seth Kellogg	Project Manager	Geosyntec	(609) 895-1400	SKellogg@geosyntec.com
Dale Prokopchak	Corporate Health and Safety Officer	Geosyntec	(804) 665-2811	DProkopchak@geosyntec.com
Livia Capaldi	Project QA Manager	Geosyntec	(609) 895-1400	LCapaldi@geosyntec.com
Jessica Evans and Caroline Kellner	Field Manager/ Project EHS Officer	Geosyntec	(609) 895-1400	JMEvans@geosyntec.com CKellner@geosyntec.com
Mary Tyler	Analytical Data QA Manager	Geosyntec	(865) 291-4699	MTyler@geosyntec.com
Elizabeth Bauer	Laboratory Project Manager	Eurofins Lancaster Laboratories Environmental, LLC	(717) 556-7290	ElizabethMBauer@eurofinsUS.com
Neil Sturchio	Laboratory Director	Environmental Isotope Geochemistry Laboratory: University of Delaware	(302) 831-8706	Sturchio@udel.com

QAPP WORKSHEET #4: PROJECT PERSONNEL SIGN-OFF SHEET

Project Personnel	Organization/Title/Role	Telephone Number	Signature*	Date QAPP Read
Seth Kellogg	Geosyntec/Project Manager	(609) 895-1400		

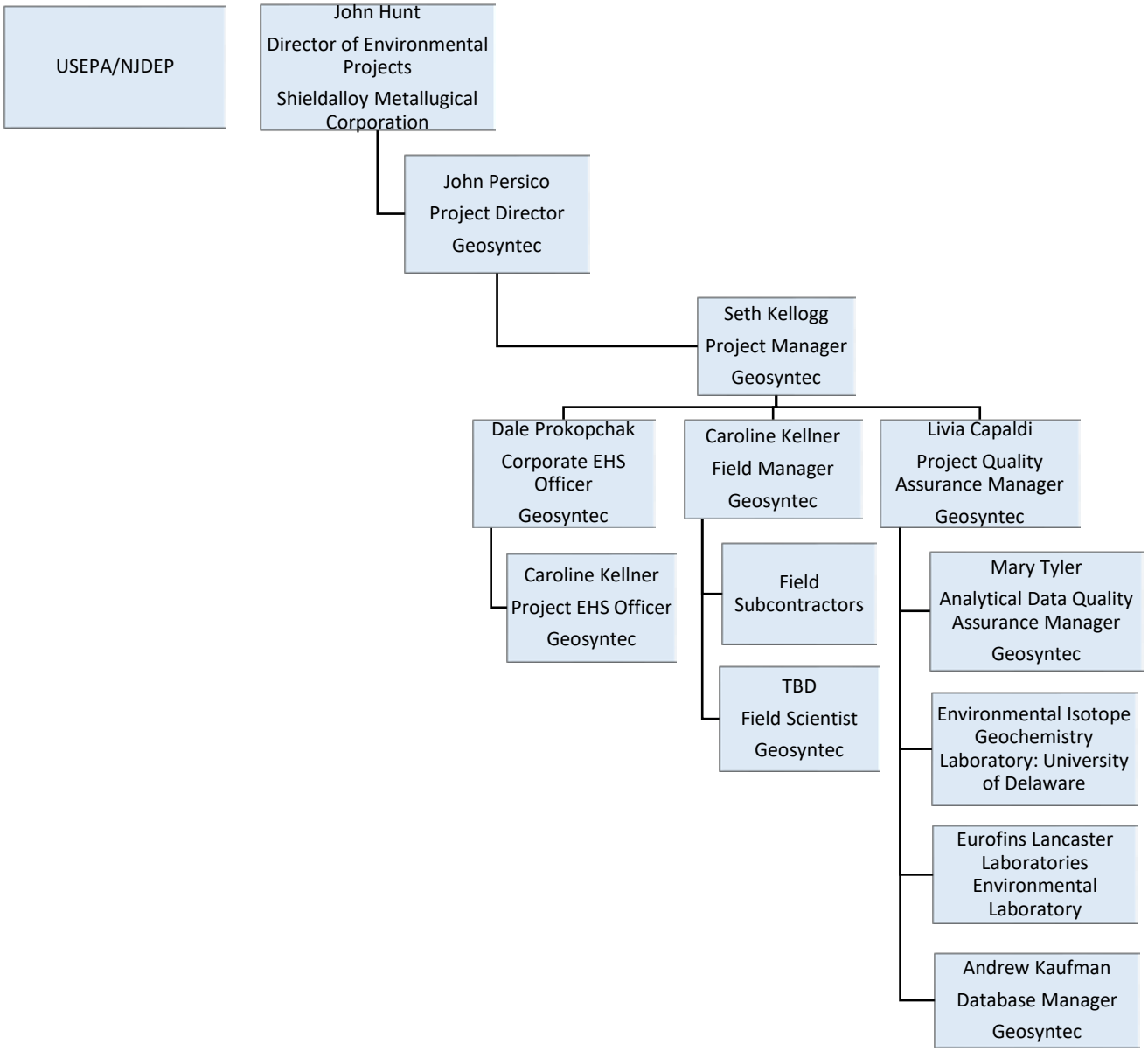
* Signature indicates personnel have read applicable QAPP sections and will perform the work as indicated herein.

Note: Additional sheets will be signed by Geosyntec field scientists and field technicians and these signatures will be maintained in the project file.

QAPP WORKSHEET #4: PROJECT PERSONNEL SIGN -OFF SHEET (CONTINUED)

Field Personnel	Organization/Title/Role	Signature*	Date QAPP Read

QAPP WORKSHEET #5: PROJECT ORGANIZATIONAL CHART



QAPP WORKSHEET #6: COMMUNICATION PATHWAYS

Communication Drivers	Responsible Affiliation	Role	Contact Information	Procedure
Approval of Amendments to QAPP	Geosyntec	Project Manager	See Worksheet #3 and #4	Obtain initial approval from Project Manager. Submit documented amendments within 10 working days for transmittal to the Respondent's Representative for submission to the EPA RPM for approval.
Approval of activities deviating from QAPP	Geosyntec	Project Manager	See Worksheet #3 and #4	Obtain initial approval from Project Manager. Submit request for deviation within 10 working days for transmittal to the Respondent's Representative for submission to the EPA Remedial Project Manager for approval.
Document Control	Geosyntec	Project Manager Project QA Manager	See Worksheet #3 and #4	The reports and formal correspondence will be reviewed by Project Manager prior to transmittal to the Respondent's Representative for submission to the EPA. Documents with analytical data prepared for submittal to EPA will be reviewed by the Project QA Manager or their designee prior to submittal to the Respondent's Representative for submission to the EPA
Stop work and initiation of stop work procedure	Geosyntec	Field Manager Project EHS Officer	See Worksheet #3 and #4	All field personnel will have stop work authority if an unsafe condition is encountered. **All stop work occurrences will be reported to the EHS Officer and the EHS Officer will forward this information on to the Project Manager using telephone and/or email as soon as possible.**
Work Stoppages	Geosyntec	Project Manager Field Manager Project EHS Officer	See Worksheet #3 and #4	The Project Manager will communicate work stoppages to the project organization within 24 hours.

QAPP WORKSHEET #6: COMMUNICATION PATHWAYS (CONTINUED)

Communication Drivers	Responsible Affiliation	Role	Contact Information	Procedure
Real time modifications, notifications, and approvals	Geosyntec	Field Manager	See Worksheet #3 and #4	Real-time modifications to the project will require the approval of the Project Manager, the Respondent's Representative and the EPA Remedial Project Manager and will be documented within 5 working days.
Reporting of health and safety issues	Geosyntec	Project EHS Officer Field Manager	See Worksheet #3 and #4	H&S issues involving an injury, a stop work procedure, a "good catch," or a condition that may result in an incident must be reported to the EHS Officer immediately. The EHS Officer will forward this information on to the Project Manager using telephone and email as soon as possible. The Project Manager will notify the Respondent's Representative and EPA Remedial Project Manager of any serious health and safety incident/issue within 24 hours of occurrence. Non-serious incidents/issues may be forwarded from the Project Manager to the Respondent's Representative and who may submit to the EPA Remedial Project Manager on a monthly basis within the monthly progress reports.
Reporting of issues related to AOC requirements.	Geosyntec	Project Manager	See Worksheet #3 and #4	Issues that prevent the collection of usable data will be reported to the Respondent Project Manager immediately.
Real time changes to sample collection or analysis procedures	Geosyntec	Field Manager Project QA Manager	See Worksheet #3 and #4	Conditions requiring variation to sampling and analysis procedures will be reported to the Field Manager within 24 hours of the condition requiring the modification. The Field Manager or Project QA Manager will report the variations to the Project Manager as appropriate.

QAPP WORKSHEET #6: COMMUNICATION PATHWAYS (CONTINUED)

Communication Drivers	Responsible Affiliation	Role	Contact Information	Procedure
Reporting issues related to data quality, including the inability to meet reporting limits	Eurofins	Laboratory PM	See Worksheet #3 and #4	Problems with the data quality will be reported to the Project Manager and Project QA Manager within 24 hours of laboratory results.
Data validation issues	Geosyntec	Analytical Data QA Manager	See Worksheet #3 and #4	Problems with data quality or data validation will be reported to the Project Manager and the QA Manager within 24 hours of the identification of the data validation issue.
Data Review Corrective Action	Geosyntec	Analytical Data QA Manager or designee	See Worksheet #3 and #4	Corrective Action Subjects: • Field Sampling Procedure • Offsite Laboratory Technical Systems Audit • Offsite Laboratory Technical Systems Audit: Laboratory Personnel • Data Quality Assessment

QAPP WORKSHEET #7: PERSONNEL RESPONSIBILITIES AND QUALIFICATIONS

Name	Project Title/Role	Organizational Affiliation	Responsibilities	Education and/or Experience Qualifications
Sherrel Henry	Remedial Project Manager	EPA Region 2	Remedial Project Manager	
John Persico	Project Director	Geosyntec	Overall project direction and completion of objectives	M.S. Geology, P.G.
Seth Kellogg	Project Manger	Geosyntec	Project administration & technical oversight	M.S. Geology, P.G.
Dale Prokopchak	Health and Safety Manager	Geosyntec	Corporate health and safety management	CIH, CSP
Mary Tyler	Analytical Data Quality Assurance Manager	Geosyntec	Data validation	M.S. Engineering
Jessica Evans and Caroline Kellner	Project EHS Officer and Field Manager	Geosyntec	Site health and safety and manage field staff	M.S. Biology B.S. Geology
Livia Capaldi	Project QA Manager	Geosyntec	Project quality assurance	M.S. Geology
Elizabeth Bauer	Laboratory Project Manager	Eurofins Lancaster Laboratories Environmental	Point of contact with Geosyntec, resolve sampling, receipt, analysis and storage issues.	
Neil Sturchio	Laboratory Director	Environmental Isotope Geochemistry Laboratory: University of Delaware	Point of contact with Geosyntec, resolve sampling, receipt, analysis and storage issues.	Ph.D. Earth and Planetary Sciences

QAPP WORKSHEET #8: SPECIALIZED PERSONNEL TRAINING REQUIREMENTS TABLE

Project Function	Specialized Training by Title or Description of Course	Personnel / Groups Receiving Training	Personnel Titles / Organizational Affiliation	Location of Training Records / Certificates
Sample Collection	40-Hour HAZWOPER Training	Field Personnel	Geosyntec	Footnote 1
SOP-specific	Project-specific SOP training	Personnel as required	Geosyntec	Field Site

1. Documentation for training is maintained at home office of employee and is available upon request

QAPP WORKSHEET #9: PROJECT PLANNING SESSION SUMMARY

The following is a summary of Project Planning sessions that have occurred:

Date of Planning Session: 3/22/2019
Location: Shieldalloy Site
Purpose: Discuss project overview & technical approach

Attendees and Role:

Name	Organization	Title/ Role	Email
Jessica Evans	Geosyntec	Staff Scientist	jmevans@geosyntec.com
Sherrel Henry	EPA	Remedial Project Manager	Henry.sherrel@epa.gov
John Hunt	SMC	Respondent Project Manager	jhunt@amg-nv.com
Katherine DeLuca	EPA/ CRC	Attorney	Deluca.katherine@epa.gov
Rachel Griffiths	EPA	Hydrogeologist	Griffiths.rachel@epa.gov
Donna L. Gaffigan	NJDEP	NJDEP Case Manager	Donna.gaffigan@DEP.NJ.GOV
Seth Kellogg	Geosyntec	Project Manager	skellogg@geosyntec.com
John Persico	Geosyntec	Project Director	jpersico@geosyntec.com

Notes/Comments: Wells designated as background will need evidence to support that they are background. Several rounds of sampling will be needed to support MNA if that approach is selected

Consensus decisions made: Project planning documents and approach are acceptable, and project planning documents should be submitted to NJDEP and EPA by 5/3/2019.

QAPP WORKSHEET #10: CONCEPTUAL SITE MODEL

This section presents an overview of the Conceptual Site Model (CSM) for OU3. A CSM is a representation of the physical, chemical, and biological processes that govern the transport of COCs from source(s) to receptor(s) within the system. The CSM provides a comprehensive current understanding of the sources of COCs found in groundwater at OU3, potential pathways for migration of the COCs, and potential receptors of exposure to the COCs in OU3.

While there are other COCs at the Site, OU3 addresses only the perchlorate COC in groundwater. Other Site COCs are being addressed as part of OU1 and OU2 and are not discussed in this CSM. As discussed in Section 1.2 of the Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation (Revised FSP OU3 SRI), solid potassium perchlorate was used as a catalyst in the furnace located in former Building D102(A). Unreacted slag from this process was disposed in the former lagoon and slag piles, which were possible secondary source areas for perchlorate.

The Site lies on the Bridgeton Formation (present in the eastern portion of the Site) and Cohansey Sand, which consist of sand and some silt. Groundwater is encountered at 4 to 27 ft bgs. Groundwater flow direction in both the upper and lower Cohansey Sand is southwest toward the Hudson Branch. Downward flow is restricted by the upper Kirkwood Formation which is encountered between 121 and 153 ft bgs. Historical monitoring wells are screened across the shallow, intermediate and deep zones of the aquifer to fully evaluate perchlorate concentrations.

Sampling was conducted by TRC from 2006 through 2011 to assess the distribution of perchlorate both on-Site and off-Site. Ten vertical profile borings (VP-1, VP-2, VP-3, VP-4, VP-10, VP-13, VP-13A, VP-14, VP-15, and VP-15A) were advanced and sampled to the southwest of the Site to determine the off-Site lateral and vertical extent of perchlorate. Based on the results of this sampling, seven permanent monitoring wells (SC30D, SC32D, SC33D, SC34D, SC35D, SC36D, and SC40D) were constructed for long-term monitoring at the furthest extent of the perchlorate plume in the south, southwest, and northwest directions. Relevant boring logs, vertical profiling logs, and well construction diagrams are included in Attachment B of the Revised FSP OU3 SRI.

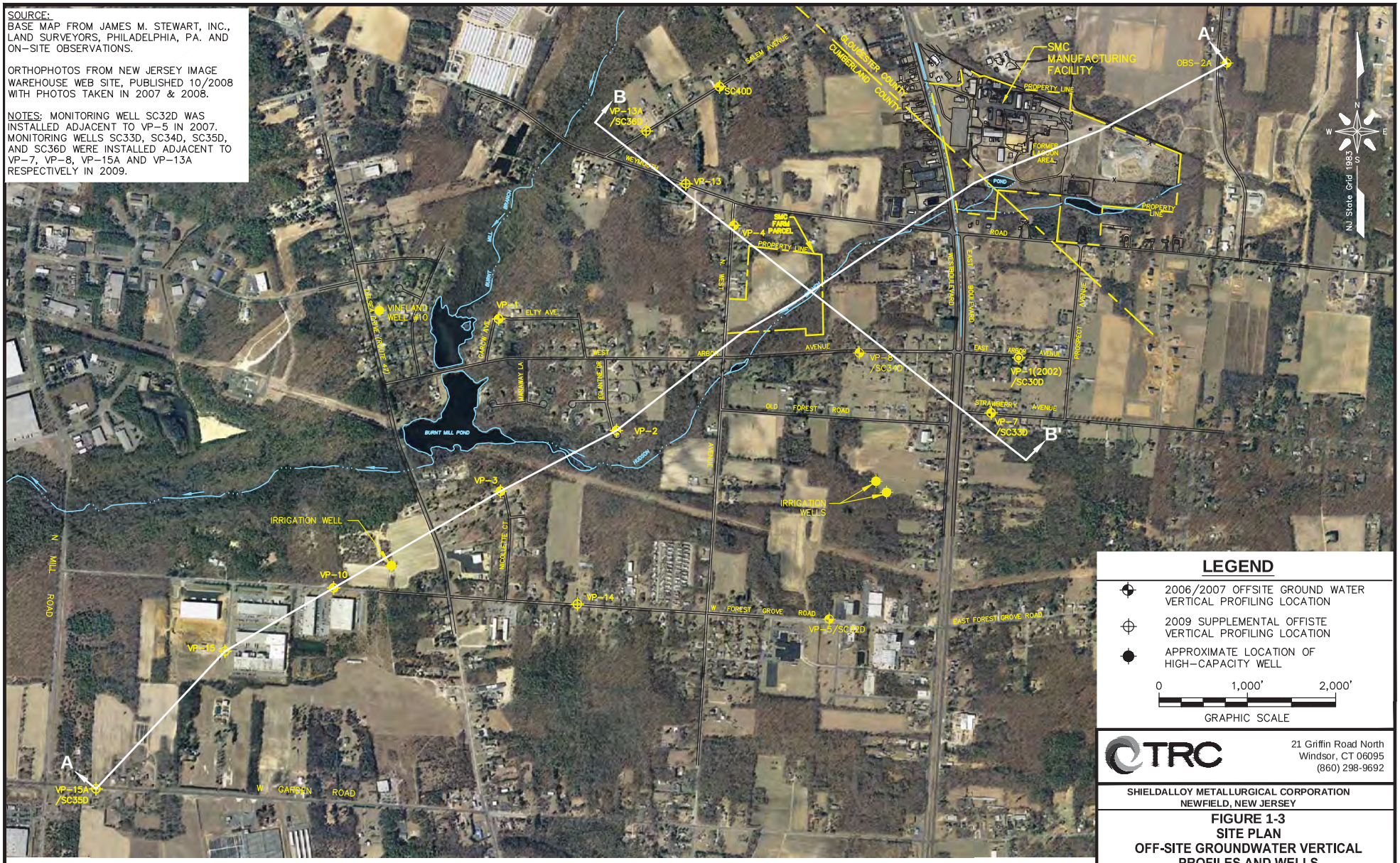
Historic data, provided in Attachment A of the Revised FSP OU3 SRI, show perchlorate concentrations in the shallow, intermediate, and deep aquifers at concentrations up to 90.5 parts per billion (ppb), 20.9 ppb, and 152 ppb, respectively. Isopleth maps and vertical profile cross sections (provided at the end of this worksheet) created from historic sampling results show the highest perchlorate concentrations located beneath the Site and at the center of the plume in the deep zone approximately half a mile southwest of the Site. The groundwater sampling results through 2011 showed that perchlorate migrated vertically from source areas at the Site to the deep zone and then migrated to the southwest in the downgradient direction. Nearby irrigation pumping wells may have influenced the local groundwater flow patterns in the vicinity of the plume.

The applicable standard for perchlorate in groundwater is the GWQS of 5 ppb. This endpoint will be protective of human receptors who may ingest groundwater on-Site and off-Site.

SOURCE:
BASE MAP FROM JAMES M. STEWART, INC., LAND SURVEYORS, PHILADELPHIA, PA. AND ON-SITE OBSERVATIONS.

ORTHOPHOTOS FROM NEW JERSEY IMAGE WAREHOUSE WEB SITE, PUBLISHED 10/2008 WITH PHOTOS TAKEN IN 2007 & 2008.

NOTES: MONITORING WELL SC32D WAS INSTALLED ADJACENT TO VP-5 IN 2007. MONITORING WELLS SC33D, SC34D, SC35D, AND SC36D WERE INSTALLED ADJACENT TO VP-7, VP-8, VP-15A AND VP-13A RESPECTIVELY IN 2009.



LEGEND

- 2006/2007 OFFSITE GROUND WATER VERTICAL PROFILING LOCATION
- 2009 SUPPLEMENTAL OFFISTE VERTICAL PROFILING LOCATION
- APPROXIMATE LOCATION OF HIGH-CAPACITY WELL

0 1,000' 2,000'

GRAPHIC SCALE

TRC
21 Griffin Road North
Windsor, CT 06095
(860) 298-9692

SHIELDALLOY METALLURGICAL CORPORATION
NEWFIELD, NEW JERSEY

FIGURE 1-3
SITE PLAN
OFF-SITE GROUNDWATER VERTICAL PROFILES AND WELLS

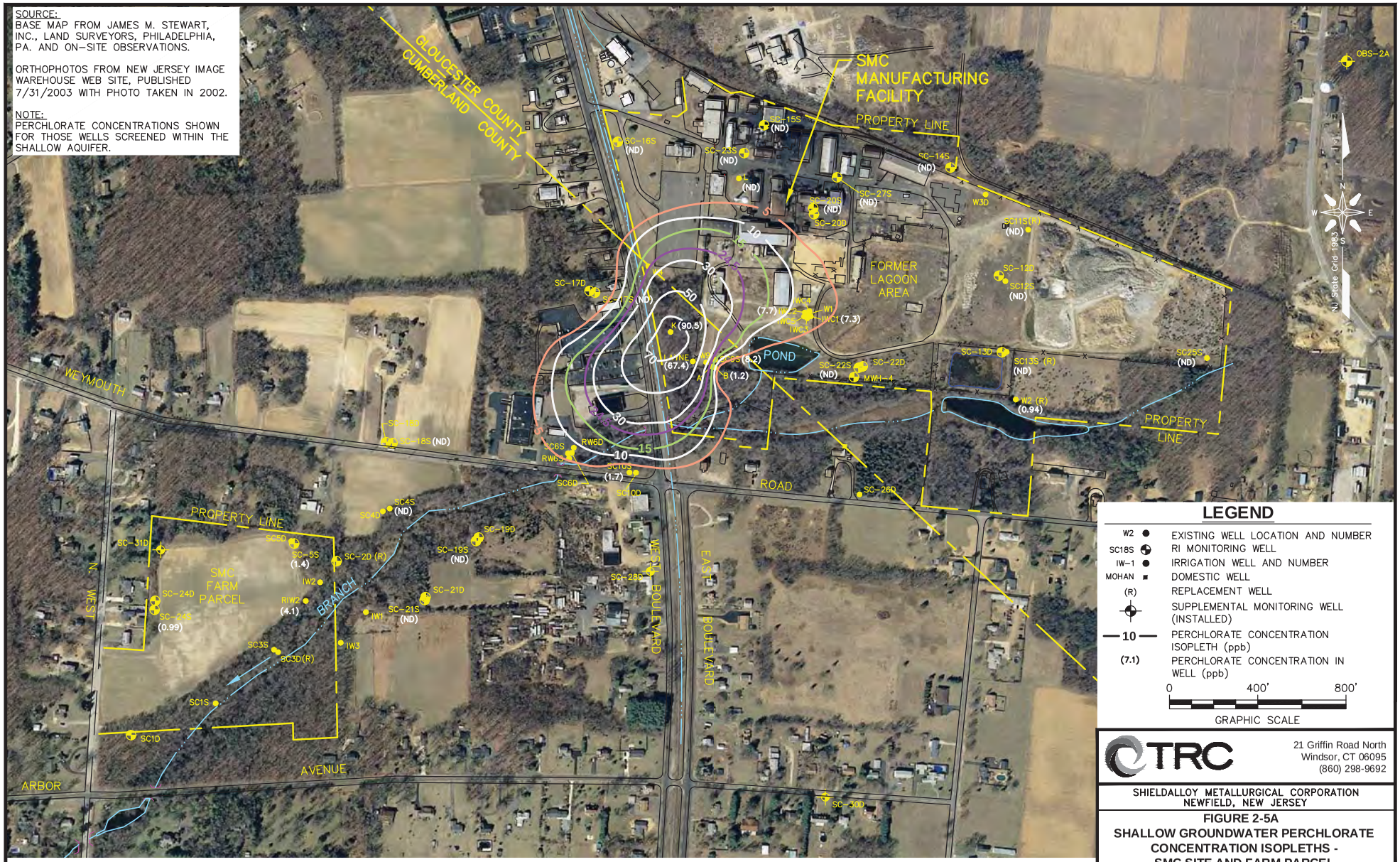
Date: 09/2016 | **Project No.** 261644.0000.000000

J:\CAD\177208\000050\
Plate-2.dwg Layout:FIGURE 2-3 June 22, 2011-10:17AM Raloma

SOURCE:
BASE MAP FROM JAMES M. STEWART, INC., LAND SURVEYORS, PHILADELPHIA, PA. AND ON-SITE OBSERVATIONS.

ORTHOPHOTOS FROM NEW JERSEY IMAGE WAREHOUSE WEB SITE, PUBLISHED 7/31/2003 WITH PHOTO TAKEN IN 2002.

NOTE:
PERCHLORATE CONCENTRATIONS SHOWN FOR THOSE WELLS SCREENED WITHIN THE SHALLOW AQUIFER.



LEGEND

W2 ●	EXISTING WELL LOCATION AND NUMBER
SC18S	RI MONITORING WELL
IW-1 ●	IRRIGATION WELL AND NUMBER
MOHAN ■	DOMESTIC WELL
(R)	REPLACEMENT WELL
⊕	SUPPLEMENTAL MONITORING WELL (INSTALLED)
—10—	PERCHLORATE CONCENTRATION ISOPLETH (ppb)
(7.1)	PERCHLORATE CONCENTRATION IN WELL (ppb)

0 400' 800'

GRAPHIC SCALE

TRC
21 Griffin Road North
Windsor, CT 06095
(860) 298-9692

SHIELDALLOY METALLURGICAL CORPORATION
NEWFIELD, NEW JERSEY

FIGURE 2-5A
SHALLOW GROUNDWATER PERCHLORATE CONCENTRATION ISOPLETHS - SMC SITE AND FARM PARCEL

Date: 09/2016 | Project No. 261644.0000.000000

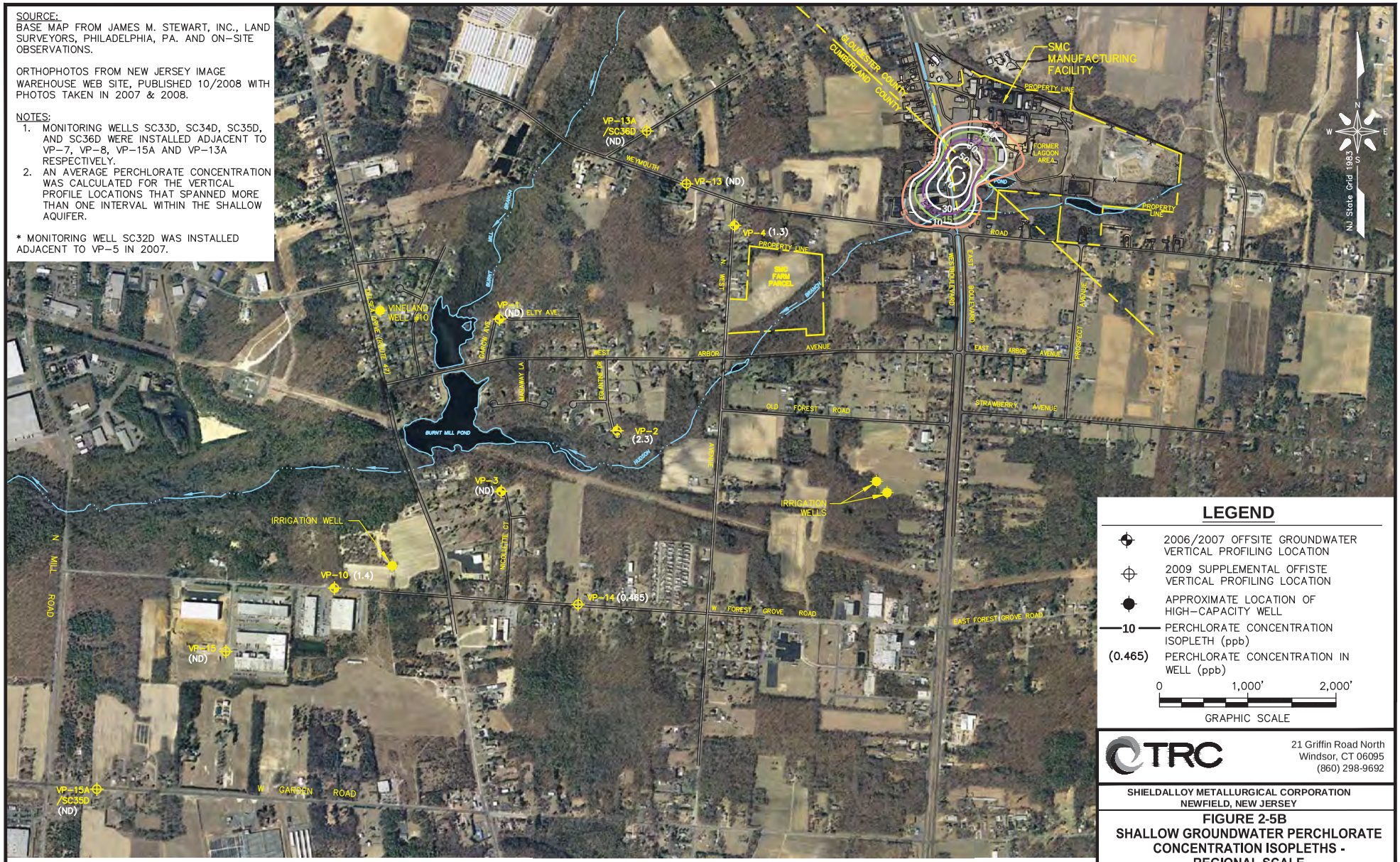
J:\CAD\171441\000050\Remedial Inv Report\
Plate-1.dwg Layout:FIGURE 10-1A November 19, 2010-1:32PM KHollenbeck

SOURCE:
BASE MAP FROM JAMES M. STEWART, INC., LAND SURVEYORS, PHILADELPHIA, PA. AND ON-SITE OBSERVATIONS.

ORTHOPHOTOS FROM NEW JERSEY IMAGE WAREHOUSE WEB SITE, PUBLISHED 10/2008 WITH PHOTOS TAKEN IN 2007 & 2008.

NOTES:
1. MONITORING WELLS SC33D, SC34D, SC35D, AND SC36D WERE INSTALLED ADJACENT TO VP-7, VP-8, VP-15A AND VP-13A RESPECTIVELY.
2. AN AVERAGE PERCHLORATE CONCENTRATION WAS CALCULATED FOR THE VERTICAL PROFILE LOCATIONS THAT SPANNED MORE THAN ONE INTERVAL WITHIN THE SHALLOW AQUIFER.

* MONITORING WELL SC32D WAS INSTALLED ADJACENT TO VP-5 IN 2007.



LEGEND

- 2006/2007 OFFSITE GROUNDWATER VERTICAL PROFILING LOCATION
- 2009 SUPPLEMENTAL OFFISTE VERTICAL PROFILING LOCATION
- APPROXIMATE LOCATION OF HIGH-CAPACITY WELL
- —10— PERCHLORATE CONCENTRATION ISOPLETH (ppb)
- (0.465) PERCHLORATE CONCENTRATION IN WELL (ppb)

0 1,000' 2,000'
GRAPHIC SCALE

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FIGURE 2-5B
SHALLOW GROUNDWATER PERCHLORATE CONCENTRATION ISOPLETHS - REGIONAL SCALE

Date: 09/2016 | Project No. 261644.0000.000000

J:\CAD\171441\000050\Remedial Inv Report\
Plate-4.dwg Layout:FIGURE 10-1B November 19, 2010-1:40PM KHollenbeck

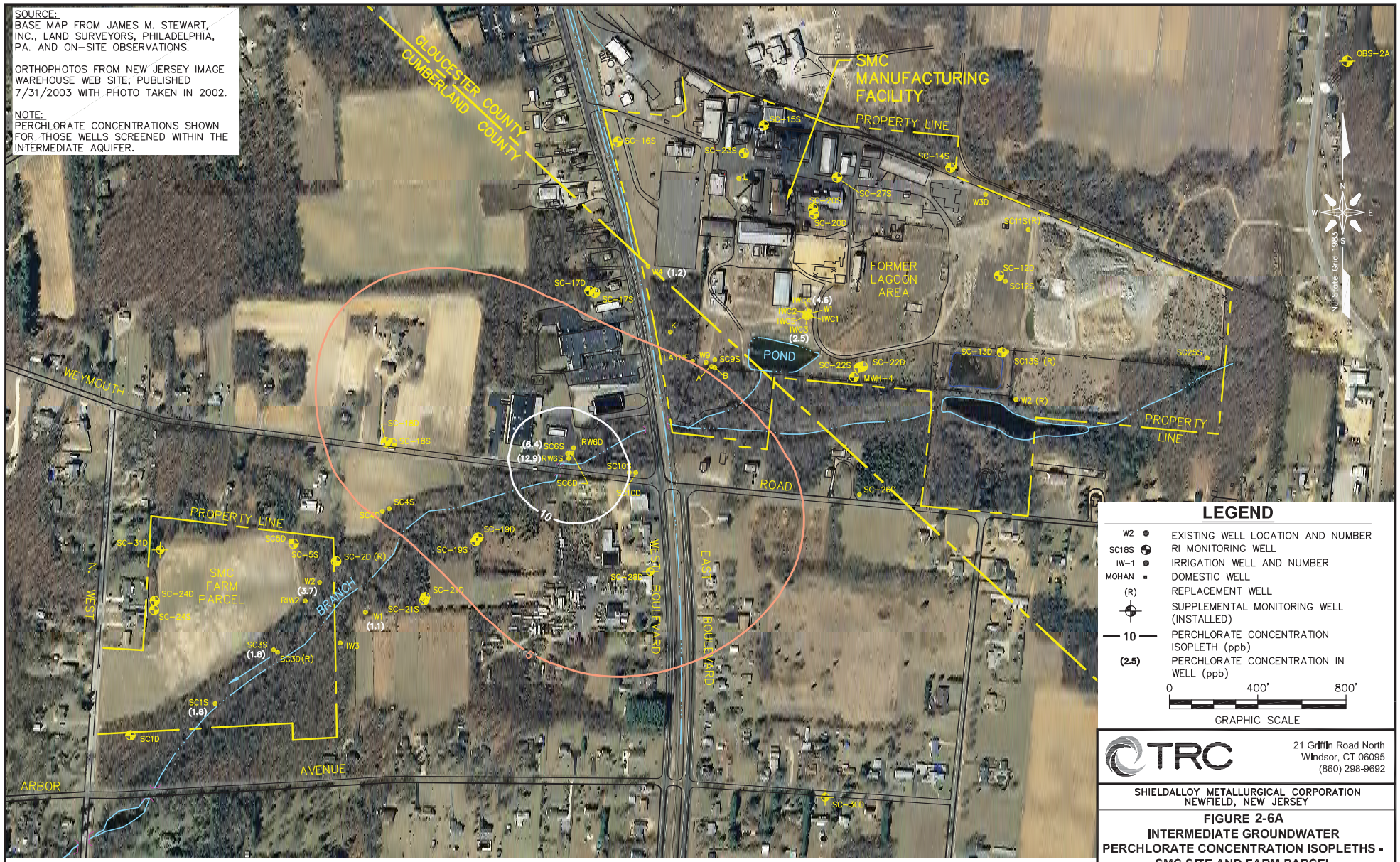
SOURCE:
BASE MAP FROM JAMES M. STEWART, INC., LAND SURVEYORS, PHILADELPHIA, PA. AND ON-SITE OBSERVATIONS.
ORTHOPHOTOS FROM NEW JERSEY IMAGE WAREHOUSE WEB SITE, PUBLISHED 7/31/2003 WITH PHOTO TAKEN IN 2002.
NOTE:
PERCHLORATE CONCENTRATIONS SHOWN FOR THOSE WELLS SCREENED WITHIN THE INTERMEDIATE AQUIFER.
GLOUCESTER COUNTY
CUMBERLAND COUNTY
SMC MANUFACTURING FACILITY
PROPERTY LINE
FORMER LAGOON AREA
POND
WEYMOUTH
ROAD
WEST BOULEVARD
EAST BOULEVARD
SMC FARM PARCEL
BRANCH
N. WEST
ARBOR
AVENUE
NJ State Grid 1983
LEGEND
W2 EXISTING WELL LOCATION AND NUMBER
SC18S RI MONITORING WELL
IW-1 IRRIGATION WELL AND NUMBER
MOHAN DOMESTIC WELL
(R) REPLACEMENT WELL
SUPPLEMENTAL MONITORING WELL (INSTALLED)
10 PERCHLORATE CONCENTRATION ISOPLETH (ppb)
(2.5) PERCHLORATE CONCENTRATION IN WELL (ppb)
0 400' 800'
GRAPHIC SCALE
TRC
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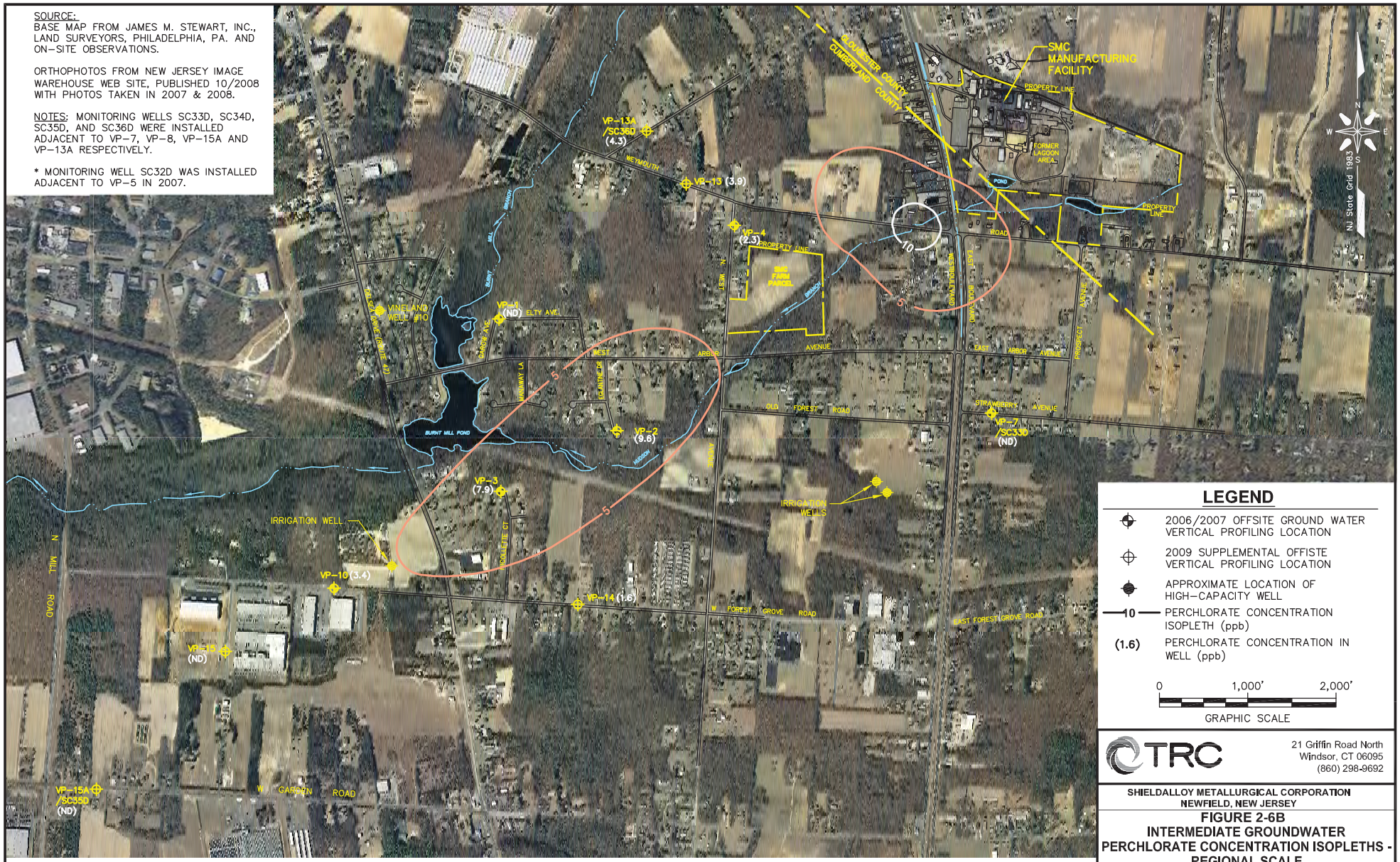
FIGURE 2-6A
INTERMEDIATE GROUNDWATER PERCHLORATE CONCENTRATION ISOPLETHS - SMC SITE AND FARM PARCEL
Date: 09/2016
Project No. 261644.0000.000000
J:\CAD\171441\000050\Remedial Inv Report\
Plate-1.dwg Layout:FIGURE 10-2A March 15, 2010-10:27AM KHollenbeck

SOURCE:
BASE MAP FROM JAMES M. STEWART, INC., LAND SURVEYORS, PHILADELPHIA, PA. AND ON-SITE OBSERVATIONS.

ORTHOPHOTOS FROM NEW JERSEY IMAGE WAREHOUSE WEB SITE, PUBLISHED 10/2008 WITH PHOTOS TAKEN IN 2007 & 2008.

NOTES: MONITORING WELLS SC33D, SC34D, SC35D, AND SC36D WERE INSTALLED ADJACENT TO VP-7, VP-8, VP-15A AND VP-13A RESPECTIVELY.

* MONITORING WELL SC32D WAS INSTALLED ADJACENT TO VP-5 IN 2007.



LEGEND

- 2006/2007 OFFSITE GROUND WATER VERTICAL PROFILING LOCATION
- 2009 SUPPLEMENTAL OFFISTE VERTICAL PROFILING LOCATION
- APPROXIMATE LOCATION OF HIGH-CAPACITY WELL
- —10— PERCHLORATE CONCENTRATION ISOPLETH (ppb)
- (1.6) PERCHLORATE CONCENTRATION IN WELL (ppb)

0 1,000' 2,000'
GRAPHIC SCALE

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FIGURE 2-6B
INTERMEDIATE GROUNDWATER PERCHLORATE CONCENTRATION ISOPLETHS - REGIONAL SCALE

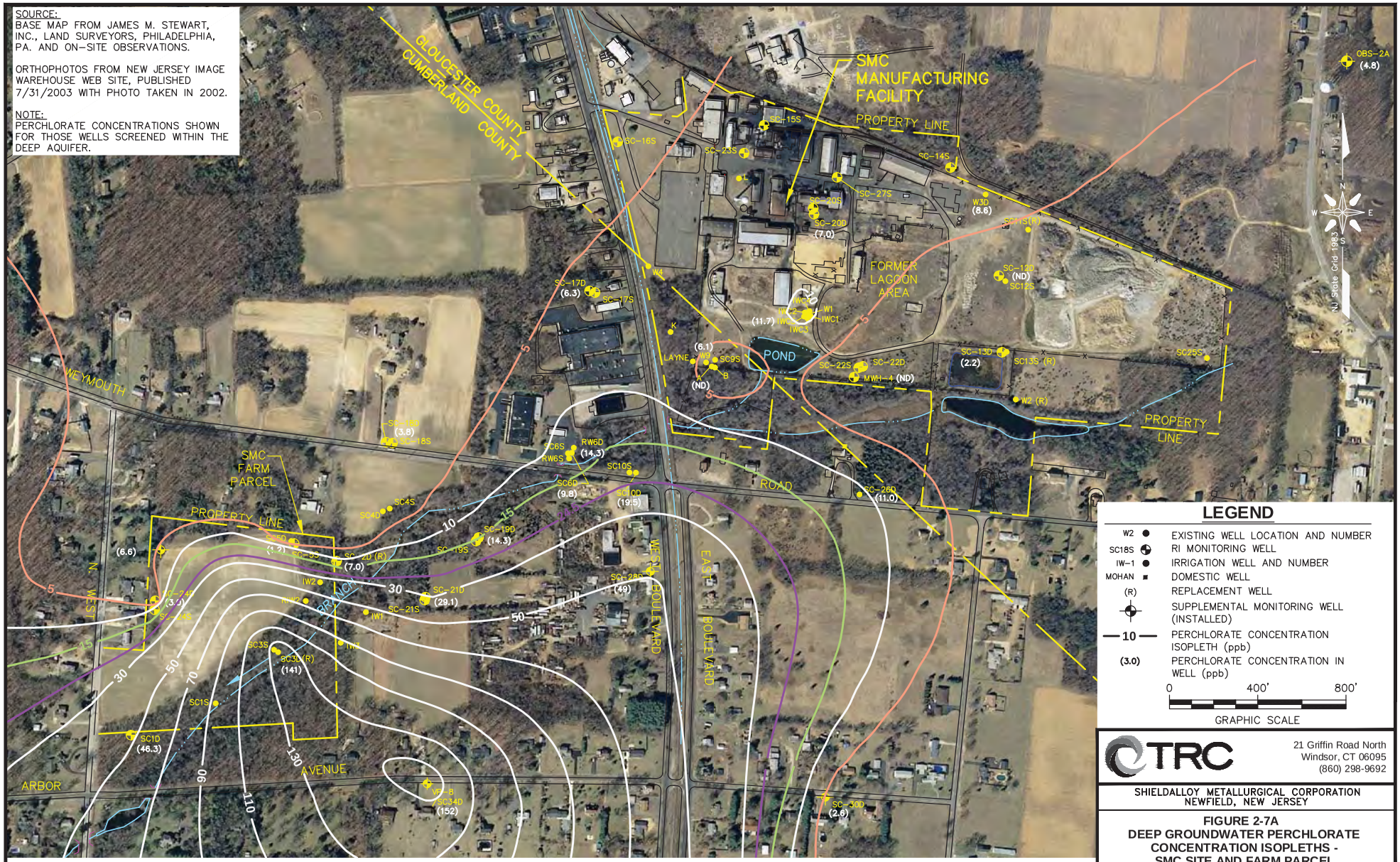
Date: 09/2016 | Project No. 261644.0000.000000

J:\CAD\171441\000050\Remedial Inv Report\
Plate-4.dwg Layout:FIGURE 10-2B March 15, 2010-10:15AM KHollenbeck

SOURCE:
BASE MAP FROM JAMES M. STEWART, INC., LAND SURVEYORS, PHILADELPHIA, PA. AND ON-SITE OBSERVATIONS.

ORTHOPHOTOS FROM NEW JERSEY IMAGE WAREHOUSE WEB SITE, PUBLISHED 7/31/2003 WITH PHOTO TAKEN IN 2002.

NOTE:
PERCHLORATE CONCENTRATIONS SHOWN FOR THOSE WELLS SCREENED WITHIN THE DEEP AQUIFER.



LEGEND

W2 ●	EXISTING WELL LOCATION AND NUMBER
SC18S ⊕	RI MONITORING WELL
IW-1 ●	IRRIGATION WELL AND NUMBER
MOHAN ■	DOMESTIC WELL
(R)	REPLACEMENT WELL
⊕	SUPPLEMENTAL MONITORING WELL (INSTALLED)
—10—	PERCHLORATE CONCENTRATION ISOPLETH (ppb)
(3.0)	PERCHLORATE CONCENTRATION IN WELL (ppb)

0 400' 800'

GRAPHIC SCALE

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FIGURE 2-7A
DEEP GROUNDWATER PERCHLORATE CONCENTRATION ISOPLETHS - SMC SITE AND FARM PARCEL

Date: 09/2016 | **Project No.** 261644.0000.000000

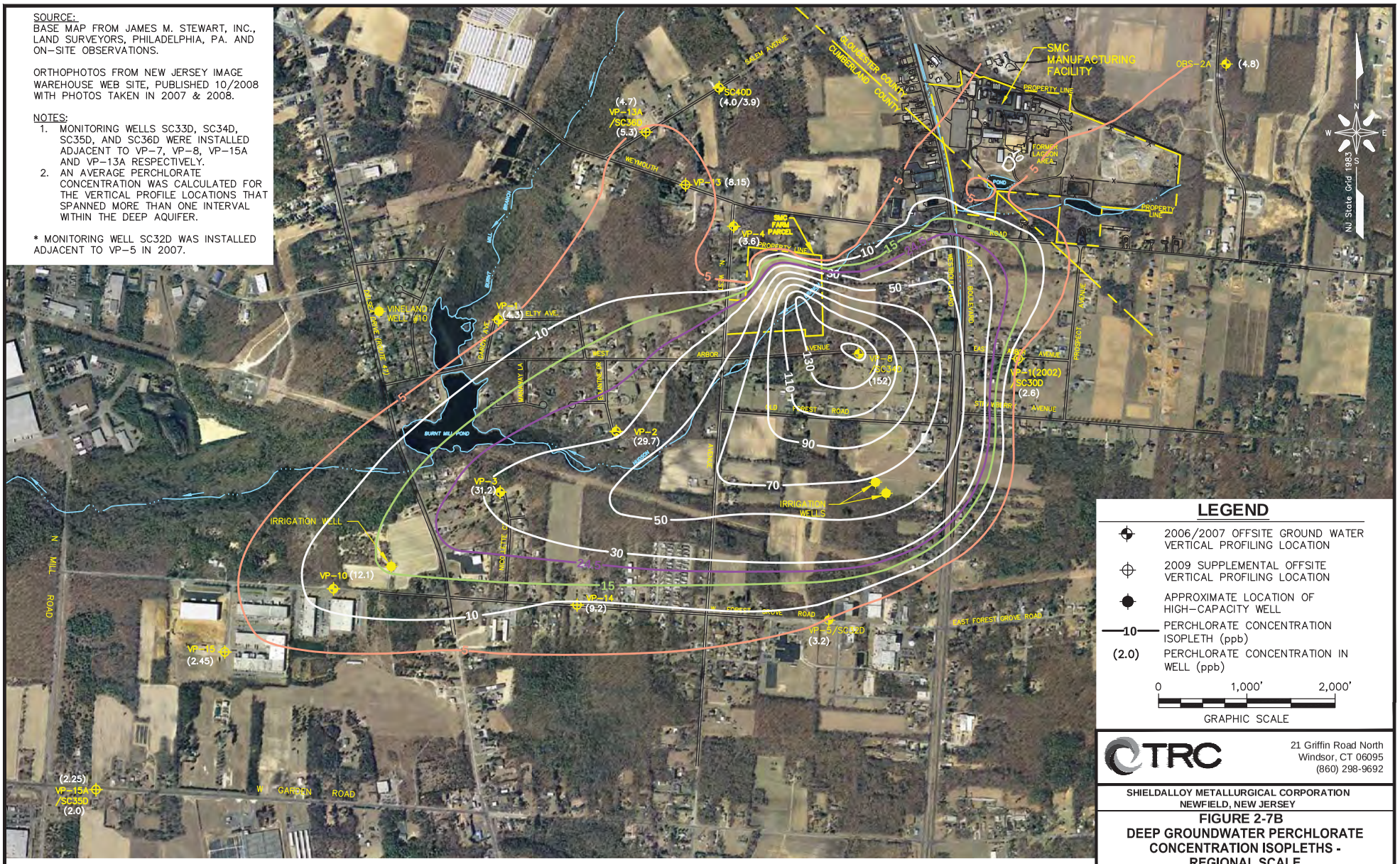
J:\CAD\177208\000050\
Plate-1.dwg Layout:FIGURE 10-3A June 21, 2011-3:16PM Raloma

SOURCE:
BASE MAP FROM JAMES M. STEWART, INC., LAND SURVEYORS, PHILADELPHIA, PA. AND ON-SITE OBSERVATIONS.

ORTHOPHOTOS FROM NEW JERSEY IMAGE WAREHOUSE WEB SITE, PUBLISHED 10/2008 WITH PHOTOS TAKEN IN 2007 & 2008.

NOTES:
1. MONITORING WELLS SC33D, SC34D, SC35D, AND SC36D WERE INSTALLED ADJACENT TO VP-7, VP-8, VP-15A AND VP-13A RESPECTIVELY.
2. AN AVERAGE PERCHLORATE CONCENTRATION WAS CALCULATED FOR THE VERTICAL PROFILE LOCATIONS THAT SPANNED MORE THAN ONE INTERVAL WITHIN THE DEEP AQUIFER.

* MONITORING WELL SC32D WAS INSTALLED ADJACENT TO VP-5 IN 2007.



LEGEND

- 2006/2007 OFFSITE GROUND WATER VERTICAL PROFILING LOCATION
- 2009 SUPPLEMENTAL OFFSITE VERTICAL PROFILING LOCATION
- APPROXIMATE LOCATION OF HIGH-CAPACITY WELL
- —10— PERCHLORATE CONCENTRATION ISOPLETH (ppb)
- (2.0) PERCHLORATE CONCENTRATION IN WELL (ppb)

0 1,000' 2,000'
GRAPHIC SCALE

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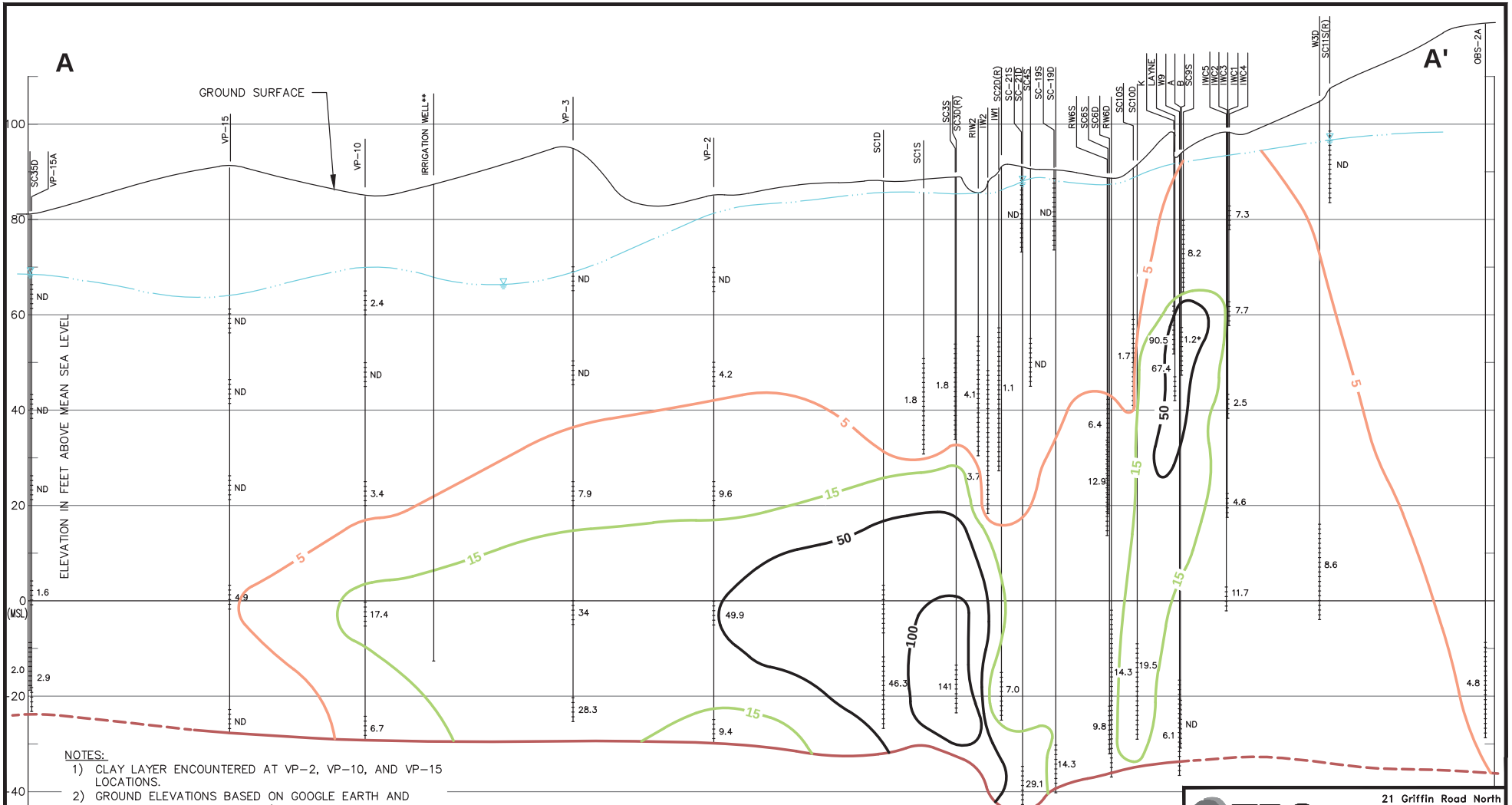
FIGURE 2-7B
DEEP GROUNDWATER PERCHLORATE CONCENTRATION ISOPLETHS - REGIONAL SCALE

Date: 09/2016 | Project No. 261644.0000.000000

J:\CAD\177208\000050\
Plate-2.dwg Layout:FIGURE 10-3B June 21, 2011-3:18PM Raloma



NOTES:

1) CLAY LAYER ENCOUNTERED AT VP-2, VP-10, AND VP-15 LOCATIONS.
2) GROUND ELEVATIONS BASED ON GOOGLE EARTH AND SURVEYED MONITORING WELL/GROUND SURFACE ELEVATIONS. VERTICAL DATUM IS NGVD 1929.
3) PERMANENT MONITORING WELL INSTALLED AT VP-8 (SC34D) AND VP-15A (SC35D) IN 2009.
4) *=PERCHLORATE RESULT OF 1.2 µg/L AT WELL B NOT USED IN DRAFTING PERCHLORATE ISOPLETHS.
5) **=IRRIGATION WELL REPORTED TO BE APPROXIMATELY 100 FEET DEEP. SCREEN INTERVAL UNKNOWN.

LEGEND

- GROUNDWATER SAMPLE INTERVAL
- 17.7 PERCHLORATE CONCENTRATION (µg/L)
- ND NOT DETECTED
- APPROXIMATE TOP OF CONFINING CLAY LAYER (DASHED WHERE INFERRED)
- APPROXIMATE WATER TABLE DEPTH
- 50 PERCHLORATE ISOPLETH (µg/L)

0 1,000' 2,000'
HORIZONTAL GRAPHIC SCALE

0 20' 40'
VERTICAL GRAPHIC SCALE
VERTICAL EXAGGERATION = 50X

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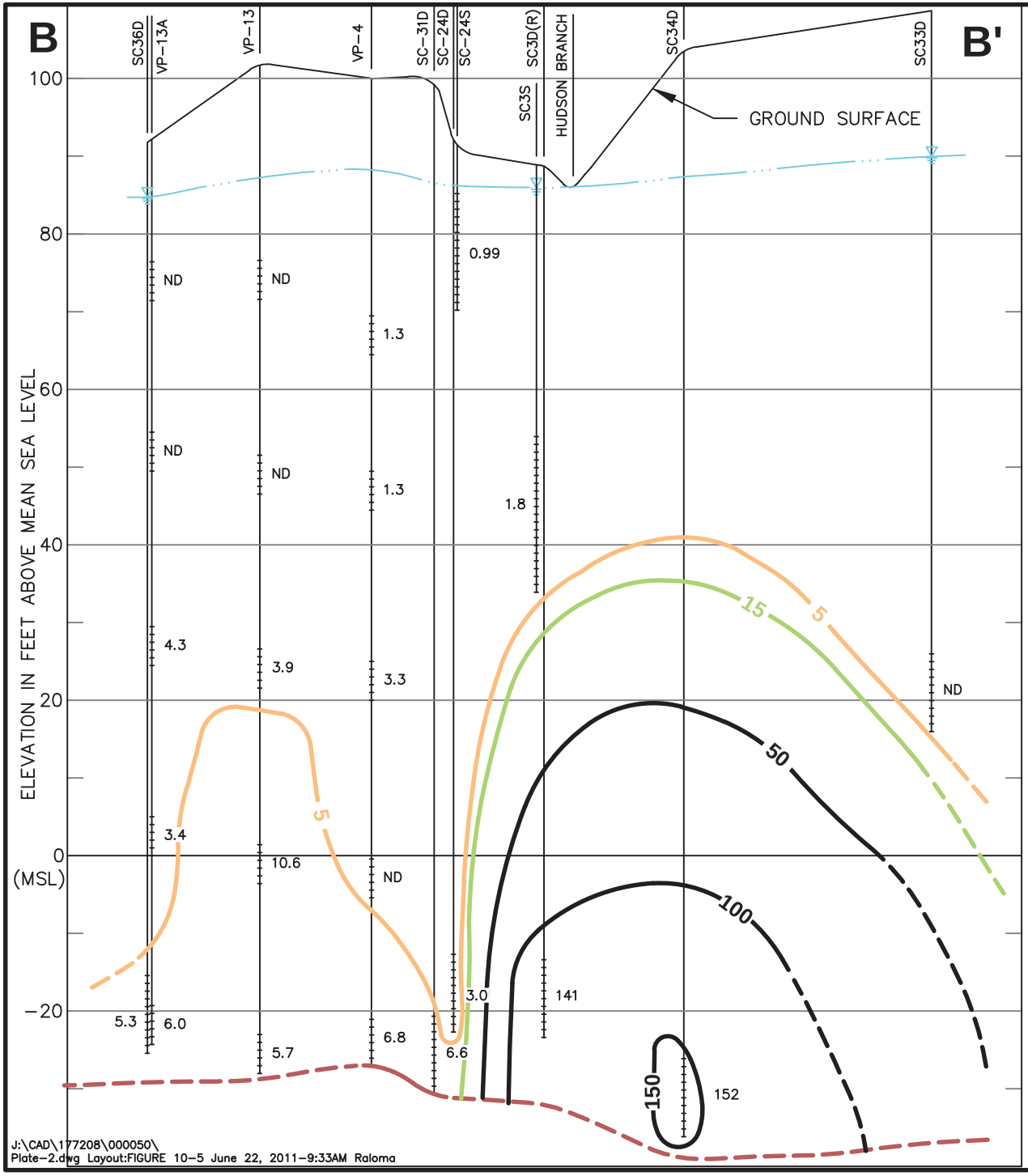
FIGURE 2-8
VERTICAL PROFILING CROSS SECTION (SC35D TO OBS-2A) PERCHLORATE CONCENTRATION

Date: 09/2016 | Project No. 261644.0000.000000

J:\CAD\177208\000050\
Plate-2.dwg Layout:FIGURE 10-4 June 22, 2011-9:29AM Raloma



J:\CAD\177208\000050\
Plate-2.dwg Layout:FIGURE 10-5 June 22, 2011-9:33AM Raloma

LEGEND

- APPROXIMATE TOP OF CONFINING CLAY LAYER (DASHED WHERE INFERRED)
- APPROXIMATE WATER TABLE DEPTH
- 50 — PERCHLORATE ISOPLETH (µg/L) (DASHED WHERE INFERRED)
- GROUNDWATER SAMPLE INTERVAL
- 17.7 — PERCHLORATE CONCENTRATION (µg/L)
- ND — NOT DETECTED

NOTES:

1) CLAY LAYER ENCOUNTERED AT VP-4 AND SC31D LOCATIONS.
2) GROUND ELEVATIONS BASED ON GOOGLE EARTH AND SURVEYED MONITORING WELL/GROUND SURFACE ELEVATIONS. VERTICAL DATUM IS NGVD 1929.
3) PERMANENT MONITORING WELLS INSTALLED AT VP-7 (SC33D) AND VP-8 (SC34D) IN 2009.

0 1,000' 2,000'

HORIZONTAL GRAPHIC SCALE

0 20' 40'

VERTICAL GRAPHIC SCALE

VERTICAL EXAGGERATION = 50X

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FIGURE 2-9
VERTICAL PROFILING CROSS SECTION (SC36D TO SC33D) PERCHLORATE CONCENTRATION

Date: 09/2016 | **Project No.** 261644.0000.000000

QAPP WORKSHEET #11: PROJECT/DATA QUALITY OBJECTIVES

The Data Quality Objective (DQO) process is a systematic planning tool that was designed to clarify the objectives of data collection and maximize efficiency during the data collection process. The DQO process is used to establish performance or acceptance criteria, which is the basis for designing a plan for collecting data of sufficient quality and quantity to support the goals of a study. There are seven steps to the DQO process as outlined in EPA/240/B-06-001, *Guidance on Systematic Planning Using the Data Quality Objectives Process* (EPA, 2006).

Step 1. State the Problem – This step defines the issues to be addressed in the RI/FS. Previous investigations at the Site have identified perchlorate in groundwater at levels above the GWQS. Nine years have elapsed since perchlorate was last investigated and it is necessary to characterize how the plume has changed to help USEPA select a remedy that will be protective of human health and meet the clean-up standards specified in CERCLA.

Step 2. Identify the Goal of the Study – This step identifies the question that the project will attempt to resolve and the actions which will be taken. As presented in Section 1.1 of the Revised FSP OU3 SRI, the goal is to investigate the current extent of the perchlorate plume, determine if the OU1 and OU2 remedies have influenced the perchlorate plume, assess the on-Site and off-Site geochemical characteristics, evaluate the USEPA concern that irrigation wells upgradient of the Site may be pulling groundwater from the Site upgradient.

Step 3. Identify Information Inputs – This step involves evaluation of existing data, identification of data gaps, and identification of new data needs. Shieldalloy has submitted several documents summarizing the previous investigations, findings of the usability assessment conducted for the data collected in these investigations, and the associated data in electronic format to the USEPA. The data include the results of previous investigations, historical uses and operations, regional geologic, hydrogeologic, and hydrologic information; surrounding land and water use; and other relevant information gathered. The quality of the data was evaluated and presented in the OU3 RIR (TRC, 2016).

New data are needed to characterize the current extent of the perchlorate plume and evaluate the current biogeochemical conditions in groundwater. The following data will be collected according to address these needs:

- Analytical parameters: perchlorate, total and dissolved iron, nitrate, sulfate, sulfide, orthophosphate, alkalinity, total organic carbon, total dissolved solids, and dissolved hydrocarbons (methane, ethane, ethene);
- Water quality parameters: pH, temperature, dissolved oxygen, oxidation reduction potential, turbidity, and specific conductivity;
- Compound Specific Isotope Analysis (CSIA);
- Gene-Trac; and
- Water level measurements.

Perchlorate undergoes natural attenuation by a variety of mechanisms, including biological reduction and physical processes including dilution and dispersion. During biological reduction, perchlorate serves as an electron acceptor, while organic carbon (either naturally present or in some cases co-released organic contaminants like oils) serves as an electron donor. The perchlorate is reduced via chlorate to chlorite, which then decomposes to chloride and oxygen. This reaction typically occurs under anaerobic conditions in the absence of oxygen. Geochemical conditions that are suitable for this reaction to occur typically include low DO concentrations, slightly negative ORP values, presence of some organic carbon, typically measured by total organic carbon (TOC) or dissolved organic carbon (DOC) analyses, and indications of conditions of nitrate reduction, sulfate reduction and/or methanogenesis. Elevated chloride and alkalinity can also in some cases provide evidence of natural attenuation of perchlorate. As such, these are all helpful indicator parameters in evaluating MNA. During biological reduction, the isotopic signature of perchlorate changes, and at some sites, CSIA analysis can provide evidence of perchlorate MNA. With respect to physical processes, perchlorate concentrations can decline as a result of dilution and dispersion. At some sites, these mechanisms are sufficient such that perchlorate plumes reach a stable size and no longer expand, allowing MNA to be a suitable remedy. While there are fewer analytical parameters that are indicative of these processes, perchlorate concentration declines can in many cases assess the contribution of these mechanisms to MNA. Additionally, Gene-Trac analysis may confirm the presence of perchlorate-reducing bacteria, which are known to be gram-negative, non-fermenting and completely oxidizing facultative anaerobes in the Proteobacteria phylum. Confirming the presence of the chlorite dismutase enzyme is also a useful indicator of natural perchlorate attenuation, but not necessary. Generally, geochemical data such as DO, pH, ORP, and nitrate can sufficiently demonstrate attenuation (ESTCP, 2008).

Step 4. Identify the Boundaries of the Study – This step is used to define the geographic and temporal boundaries. The boundary of the study area is the extent of the perchlorate plume resulting from Site activities. Sampling activities are expected to start in fall of 2020 and may be continued based upon the results of the initial investigation.

Step 5. Develop the Analytic Approach – The analytic approach summarizes how the information collected during the RI will guide the selection of an appropriate remedy. Samples will be collected and analyzed according to the sampling design provided in Worksheet #17 of this Quality Assurance Project Plan (QAPP). The below table describes how the data inputs will be used to guide remedy selection.

Perchlorate	Biogeochemical Parameters (1) and Water Quality Parameters (2)	Groundwater Level Measurements	Compound Specific Isotope Analysis
If the perchlorate concentrations at wells along the perimeter of the plume are less than 5 ppb then the plume will be considered delineated. If not, then additional wells may be installed to delineate the plume.	If the biogeochemical parameter data support natural attenuation, then natural attenuation will be considered as a remedy. If not, then natural attenuation will not be considered as a remedy.	If the groundwater level data are consistent, then the direction of groundwater flow will be determined. If not, then additional groundwater elevation data may be collected.	If the data show evidence of perchlorate with isotopic weights similar to natural sources found in fertilizer, then this information will be used to support the assumption that perchlorate is present in the background. If not, then perchlorate may not be present in the background.

1. Biogeochemical parameters - total and dissolved iron, nitrate, sulfate, sulfide, orthophosphate, alkalinity, total organic carbon, total dissolved solids, and dissolved hydrocarbons (methane, ethane, ethene)
2. Water quality parameters - pH, temperature, dissolved oxygen, oxidation reduction potential, turbidity, and specific conductivity

Step 6. Specify Performance or Acceptance Criteria – Uncertainty is present in all measurement data, and this step sets the standards at which the degree of uncertainty is acceptable. Project-specific standards details regarding the precision and accuracy control limits for each of the target analytes and matrices, as well as the overall project goals for completeness and representativeness are described in this QAPP.

Step 7. Develop the Plan for Obtaining Data – Worksheets 11 and 17 provide detailed information for collection of data sufficient to delineate perchlorate in groundwater. The Revised FSP OU3 SRI includes maps depicting sampling locations; a detailed description of the sampling analysis and testing to be performed, including sampling methods, analytical and testing methods, and frequency of sampling; and a description of how sampling data will be submitted to the USEPA.

QAPP WORKSHEET #12: MEASUREMENT PERFORMANCE CRITERIA

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group or Method: Alkalinity by SM 2320B-2011 or EPA 310.1; WI11475
Concentration Level: Low

Data Quality Indicators (DQIs)	Measurement Performance Criteria	QC Sample and/or Activity Used to Assess Measurement Performance	QC Sample Assesses Error for Sampling (S), Analytical (A) or Both (S&A)
Accuracy/Bias	Laboratory statistical window	Laboratory Control Spike/Matrix Spike, Method Detection Limit Study	A
Accuracy/Laboratory Contamination	No analytes detected > LOQ or >1/10 the amount measured in any sample	Method Blank	A
Precision	Laboratory statistical RPD	Lab Duplicate	A
Precision	RPD <30%	Field Duplicate	S & A
Accuracy/Bias	No detected target compounds	Field Blank	S & A
Representativeness/Completeness	Samples collected and analyzed as described in the Revised FSP OU3 SRI and this QAPP Data Completeness > 90%	Data Completeness Check	S & A
Sensitivity	Detection limits ≤ to Project Action Limits (See Worksheet #15)	Detection limits	A

Acronym list
Revised FSP OU3 SRI – Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation
LOQ - limit of quantification
RPD - relative percent difference
QAPP – Quality Assurance Project Plan

QAPP WORKSHEET #12: MEASUREMENT PERFORMANCE CRITERIA (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group or Method: Sulfide by SM 4500 S2D-2011 or EPA 376.2; WI11483
Concentration Level: Low

Data Quality Indicators (DQIs)	Measurement Performance Criteria	QC Sample and/or Activity Used to Assess Measurement Performance	QC Sample Assesses Error for Sampling (S), Analytical (A) or Both (S&A)
Accuracy/Bias/Precision	Laboratory statistical or method window and RPD, whichever is tighter	Laboratory Control Spike/Matrix Spike and their Duplicates, Method Detection Limit Study	A
Accuracy/Laboratory Contamination	No analytes detected > 1/2 LOQ or >1/10 the amount measured in any sample	Method Blank	A
Precision	Laboratory statistical RPD	Lab Duplicate	A
Precision	RPD <30%	Field Duplicate	S & A
Accuracy/Bias	No detected target compounds	Field Blank	S & A
Representativeness/Completeness	Samples collected and analyzed as described in the Revised FSP OU3 SRI and this QAPP Data Completeness > 90%	Data Completeness Check	S & A
Sensitivity	Detection limits ≤ to Project Action Limits (See Worksheet #15)	Detection limits	A

Acronym list
Revised FSP OU3 SRI – Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation
LOQ - limit of quantification
RPD - relative percent difference
QAPP – Quality Assurance Project Plan

QAPP WORKSHEET #12: MEASUREMENT PERFORMANCE CRITERIA (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group or Method: Wet Chemistry – Inorganic Ions by IC (NO3, SO4) by EPA 300.0/9056; WI11626 Concentration Level: Low

Data Quality Indicators (DQIs)	Measurement Performance Criteria	QC Sample and/or Activity Used to Assess Measurement Performance	QC Sample Assesses Error for Sampling (S), Analytical (A) or Both (S&A)
Accuracy/Bias	Method limits	Laboratory Control Spike/Matrix Spike, Method Detection Limit Study	A
Accuracy/Laboratory Contamination	No analytes detected <MDL or >1/10 the amount measure in any sample.	Method Blanks	A
Precision	Laboratory statistical	Lab Duplicate	A
Precision	RPD <30%	Field Duplicate	S & A
Accuracy/Bias	No detected target compounds	Field Blank	S & A
Representativeness/Completeness	Samples collected and analyzed as described in the Revised FSP OU3 SRI and this QAPP Data Completeness > 90%	Data Completeness Check	S & A
Sensitivity	Detection limits ≤ to Project Action Limits (See Worksheet #15)	Detection limits	A

Acronym list
Revised FSP OU3 SRI – Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation
MDL - method detection limit
RPD - relative percent difference
QAPP – Quality Assurance Project Plan

QAPP WORKSHEET #12: MEASUREMENT PERFORMANCE CRITERIA (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group or Method: Orthophosphate as Phosphorous by EPA 365.3; WI11511
Concentration Level: Low

Data Quality Indicators (DQIs)	Measurement Performance Criteria	QC Sample and/or Activity Used to Assess Measurement Performance	QC Sample Assesses Error for Sampling (S), Analytical (A) or Both (S&A)
Accuracy/Bias	Laboratory statistical windows	Laboratory Control Spike/Matrix Spike, Method Detection Limit Study	A
Accuracy/Laboratory Contamination	No analytes detected > LOQ or >1/10 the amount measured in any sample	Method Blank	A
Precision	Laboratory statistical RPD	Lab Duplicate	A
Precision	RPD <30%	Field Duplicate	S & A
Accuracy/Bias	No detected target compounds	Field Blank	S & A
Representativeness/Completeness	Samples collected and analyzed as described in the Revised FSP OU3 SRI and this QAPP Data Completeness > 90%	Data Completeness Check	S & A
Sensitivity	Detection limits ≤ to Project Action Limits (See Worksheet #15)	Detection limits	A

Acronym list
Revised FSP OU3 SRI – Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation
LOQ - limit of quantification
RPD - relative percent difference
QAPP – Quality Assurance Project Plan

QAPP WORKSHEET #12: MEASUREMENT PERFORMANCE CRITERIA (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group or Method: Total Organic Carbon by SM 5310C/EPA 415.1; WI11637
Concentration Level: Low

Data Quality Indicators (DQIs)	Measurement Performance Criteria	QC Sample and/or Activity Used to Assess Measurement Performance	QC Sample Assesses Error for Sampling (S), Analytical (A) or Both (S&A)
Accuracy/Bias	Laboratory statistical limits	Laboratory Control Spike/Matrix Spike, Method Detection Limit Study	A
Accuracy/Laboratory Contamination	No analytes detected > MDL or >1/10 the amount measured in any sample	Method Blank	A
Precision	Laboratory statistical RPD	Lab Duplicate	A
Precision	RPD <30%	Field Duplicate	S & A
Accuracy/Bias	No detected target compounds	Field Blank	S & A
Representativeness/Completeness	Samples collected and analyzed as described in the Revised FSP OU3 SRI and this QAPP Data Completeness > 90%	Data Completeness Check	S & A
Sensitivity	Detection limits ≤ to Project Action Limits (See Worksheet #15)	Detection limits	A

Acronym list
Revised FSP OU3 SRI – Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation
MDL - method detection limit
RPD - relative percent difference
QAPP – Quality Assurance Project Plan

QAPP WORKSHEET #12: MEASUREMENT PERFORMANCE CRITERIA (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group by Method/SOP: Dissolved Hydrocarbons (Methane, Ethane, Ethene) by RSK175 or SW-846 8015C or D/WI9796
Concentration Level: Low

Data Quality Indicators (DQIs)	Measurement Performance Criteria	QC Sample and/or Activity Used to Assess Measurement Performance	QC Sample Assesses Error for Sampling (S), Analytical (A) or Both (S&A)
Accuracy	Laboratory statistical windows	Surrogate Spike	A
Accuracy/Bias/Precision	Laboratory statistical limits	Laboratory Control Spike/Matrix Spike and their Duplicates, Method Detection Limit Study	A
Accuracy/Laboratory Contamination	No analytes detected > RL or >1/10 the amount measured in any sample	Method Blank	A
Precision	RPD <30%	Field Duplicate	S & A
Accuracy/Bias	No detected target compounds	Field Blank	S & A
Accuracy/Transport Contamination	No detected target compounds	Trip Blank	A
Representativeness/Completeness	Samples collected and analyzed as described in the Revised FSP OU3 SRI and this QAPP Data Completeness > 90%	Data Completeness Check	S & A
Sensitivity	Detection limits ≤ to Project Action Limits (See Worksheet #15)	Detection limits	A

Acronym list
Revised FSP OU3 SRI – Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation
RL – reporting limit
RPD - relative percent difference
QAPP – Quality Assurance Project Plan

QAPP WORKSHEET #12: MEASUREMENT PERFORMANCE CRITERIA (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group by Method/SOP: Wet Chemistry – Total Dissolved Solids (TDS) by SM 2540 C-2011; WI11597
Concentration Level: Low

Data Quality Indicators (DQIs)	Measurement Performance Criteria	QC Sample and/or Activity Used to Assess Measurement Performance	QC Sample Assesses Error for Sampling (S), Analytical (A) or Both (S&A)
Accuracy	Laboratory statistical windows	Surrogate Spike	A
Accuracy/Bias/Precision	Laboratory statistical limits	Laboratory Control Spike/Matrix Spike and their Duplicates, Method Detection Limit Study	A
Accuracy/Laboratory Contamination	No analytes detected > RL or >1/10 the amount measured in any sample	Method Blank	A
Precision	RPD <30%	Field Duplicate	S & A
Accuracy/Bias	No detected target compounds	Field Blank	S & A
Accuracy/Transport Contamination	No detected target compounds	Trip Blank	S & A
Representativeness/Completeness	Samples collected and analyzed as described in the Revised FSP OU3 SRI and this QAPP Data Completeness > 90%	Data Completeness Check	S & A
Sensitivity	Detection limits ≤ to Project Action Limits (See Worksheet #15)	Detection limits	A

Acronym list
Revised FSP OU3 SRI – Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation
RL – reporting limit
RPD - relative percent difference
QAPP – Quality Assurance Project Plan

QAPP WORKSHEET #12: MEASUREMENT PERFORMANCE CRITERIA (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group by Method/SOP: Metals (Total and Dissolved Iron)- ICP/MS by EPA 200.8 WI11933
Concentration Level: Low

Data Quality Indicators (DQIs)	Measurement Performance Criteria	QC Sample and/or Activity Used to Assess Measurement Performance	QC Sample Assesses Error for Sampling (S), Analytical (A) or Both (S&A)
Accuracy/Bias/Precision	Laboratory Statistical Limits; RPD ≤20%	Laboratory Control Spike/Laboratory Control Spike Duplicate, Method Detection Limit Study	A
Accuracy/Bias/Precision	Laboratory Statistical Limits; RPD ≤20%	Matrix Spike/Matrix Spike Duplicate	A
Accuracy/Laboratory Contamination	No analytes detected > 1/2 LOQ or 2.2x MDL, whichever is greater, or >1/10 the amount measured in any sample.	Method Blank	A
Precision	RPD ≤20%	Lab Duplicate	A
Precision	RPD <30%	Field Duplicate	S & A
Accuracy/Bias	No detected target compounds	Field Blank	S & A
Representativeness/Completeness	Samples collected and analyzed as described in the Revised FSP OU3 SRI and this QAPP Data Completeness > 90%	Data Completeness Check	S & A
Sensitivity	Detection limits ≤ to Project Action Limits (See Worksheet #15)	Detection limits	A

Acronym list
Revised FSP OU3 SRI – Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation
LOQ - limit of quantification
MDL - method detection limit
RPD - relative percent difference
QAPP – Quality Assurance Project Plan

QAPP WORKSHEET #12: MEASUREMENT PERFORMANCE CRITERIA (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group by Method/SOP: Perchlorate by SW-846 6850 WI9989
Concentration Level: Low

Data Quality Indicators (DQIs)	Measurement Performance Criteria	QC Sample and/or Activity Used to Assess Measurement Performance	QC Sample Assesses Error for Sampling (S), Analytical (A) or Both (S&A)
Accuracy/Bias/Precision	Laboratory statistical limits	Laboratory Control Spike/Matrix Spike and their Duplicates, Method Detection Limit Study	A
Accuracy/Laboratory Contamination	No analytes detected > RL or >1/10 the amount measured in any sample	Method Blank	A
Precision	RPD <30%	Field Duplicate	S & A
Accuracy/Bias	No detected target compounds	Field Blank	S & A
Representativeness/Completeness	Samples collected and analyzed as described in the Revised FSP OU3 SRI and this QAPP Data Completeness > 90%	Data Completeness Check	S & A
Sensitivity	Detection limits ≤ to Project Action Limits (See Worksheet #15)	Detection limits	A

Acronym list
Revised FSP OU3 SRI – Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation
RL – reporting limit
RPD - relative percent difference
QAPP – Quality Assurance Project Plan

QAPP WORKSHEET #12: MEASUREMENT PERFORMANCE CRITERIA (CONTINUED)

Laboratory: Environmental Isotope Geochemistry Laboratory: University of Delaware, Newark, DE
Matrix: Groundwater
Analytical Group by Method/SOP: CSIA Perchlorate analysis
Concentration Level: Low

Data Quality Indicators (DQIs)	Measurement Performance Criteria	QC Sample and/or Activity Used to Assess Measurement Performance	QC Sample Assesses Error for Sampling (S), Analytical (A) or Both (S&A)
Accuracy/Bias/Precision	Laboratory statistical limits	Normalization using $KClO_4$ isotopic reference materials	A
Accuracy/Bias/Precision	Laboratory statistical limits	Continuing Calibration Verification	A
Accuracy/ Bias	Laboratory statistical limits	Comparison of $KClO_4$ isotopic reference materials (USGS37, USGS38, USGS38) to certified specifications	A
Precision	RPD <30%	Field Duplicate	S
Accuracy/Bias	N/A	The sampling protocol is designed to concentrate the $KClO_4$ sample mass to overwhelm any noise associated with field contamination[1].	S & A
Representativeness/Completeness	Samples collected and analyzed as described in the Revised FSP OU3 SRI and this QAPP Data Completeness > 90%	Data Completeness Check	S & A
Sensitivity	N/A	Sample result is reported as a ratio rather than an absolute value therefore there is no detection limit.	A

1. Field blanks are only recommended for CSIA analysis if the groundwater concentrations are in the mg/L range. Otherwise, the unique method of sample collection onto columns rather than collection of purge water in sample bottles is considered sufficient to avoid field blank interference. We do not anticipate any results in the mg/L range, and therefore no field blanks are planned.

Acronym list

Revised FSP OU3 SRI – Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation
RPD - relative percent difference
QAPP – Quality Assurance Project Plan

QAPP WORKSHEET #14: SUMMARY OF PROJECT TASKS

Sampling Tasks:

Perchlorate was last investigated in 2011, at which time the groundwater concentrations exceeded the Groundwater Quality Standard (GWQS) of 5 ppb (USEPA reference). The overall objective of this investigation is to determine the extent of the perchlorate plume:

- Collect groundwater samples for perchlorate analysis to delineate the current extent of the perchlorate plume;
- Collect groundwater samples for geochemical analysis to characterize the geochemical properties of the subsurface;
- Collect water level measurements on site to assess groundwater flow;
- Collect field parameters, specifically temperature, pH, specific conductivity, dissolved oxygen (DO), turbidity, and oxidation reduction potential (ORP),
- Collect groundwater samples for Compound-Specific Isotope Analysis (CSIA) analysis to evaluate the presence and source of background perchlorate; and
- Collect groundwater samples for Gene-trac analysis to assess the potential for biological degradation of perchlorate in the subsurface.

See Worksheet 17 for an overview of the conceptual basis and rationale for characterization for each task, and Worksheet 18 for a discussion of the investigative methods.

Analytical Tasks:

- Groundwater elevation measurements
- Field geochemistry: pH, DO, ORP, specific conductance, turbidity and temperature by flow through water quality meter
- Groundwater analytical tasks to be analyzed by Eurofins Lancaster Laboratories Environmental will include:
    - Perchlorate via SW-846 6850
    - Metals (Total & Dissolved Iron) via USEPA Method 200.8
    - Dissolved Hydrocarbons (Methane, Ethane, Ethene) via RSK175 or SW-846 8015C
    - Total Dissolved Solids by SM 2540 C-2011
    - Total Organic Carbon via SM 5310C/ EPA 415.1
    - Orthophosphate as Phosphorous via EPA 365.3
    - Inorganic Ions by IC (NO_3 and SO_4) by EPA 300.0/9056
    - Sulfide by SM4500 S2D/ EPA 376.2
    - Alkalinity by SM 2320B-2011 or EPA 310.1
- Groundwater analytical tasks to be analyzed by Environmental Isotope Geochemistry Laboratory: University of Delaware will include Compound Specific Isotope Analysis

- Groundwater analytical tasks to be analyzed by SiREM will include Gene-Trac®

QAPP WORKSHEET #14: SUMMARY OF PROJECT TASKS (CONTINUED)

Quality Control (QC) Tasks:

For all samples collected for analysis by Eurofins Lancaster Laboratories Environmental, equipment blanks and field blanks will be collected to determine if contamination of samples has occurred in the field and, if possible, to quantify the extent of the impact on field samples. Trip blanks will be submitted along with all dissolved hydrocarbon samples at a frequency of one per cooler containing dissolved hydrocarbon samples. Field duplicate samples and matrix spike/matrix spike duplicate (MS/MSD) samples will also be collected (see Worksheet #20 for QC Sample frequency). The field duplicate QC samples will be submitted as blind duplicates with only the date collected recorded on the chain of custody (COC). The samples will be identified as duplicate, trip blank, equipment blank, and MS/MSD samples in the final report.

For all samples collected for analysis by University of Delaware, equipment, trip, and field blanks are not feasible given the method of sampling and would not provide a meaningful assessment of contamination since the sample result is provided as an isotopic ratio, rather than an absolute value. Additionally, the analysis method does not allow for MS/MSD analysis, therefore they will not be collected. The sample collection method is designed to collect a sufficient mass of perchlorate within the sample column by purging a large volume of sample water through the column so as to reduce the potential for interference from contamination. Field duplicate samples will be collected and submitted to the lab as blind duplicates with only the collection date recorded on the COC.

For all samples collected for analysis by SiREM no QC samples will be collected. The results from the Gene-Trac® analyses will not be used for any quantitative decisions on site; however, the standard control sample QC results will be included with the reported results. The data will be used to inform decisions about the feasibility of various perchlorate remedies on site based on the presence or absence of certain biological populations which can degrade perchlorate.

A summary of the field QC samples to be collected during the sampling program are presented as follows:

- Trip blanks (for dissolved hydrocarbons only);
- Equipment blanks consisting of laboratory-supplied analyte-free water poured over or pumped through groundwater sampling equipment; Field blanks consisting of laboratory-supplied analyte free water poured into sample containers in the field for all analyses except for CSIA and Gene-Trac®;
- Field duplicate samples for all groundwater samples except for Gene-Trac®; and
- MS/MSD samples for all groundwater samples except for CSIA and Gene-Trac®.

QAPP WORKSHEET #14: SUMMARY OF PROJECT TASKS (CONTINUED)

Data Management

Data are generated from three primary pathways: i) data derived from field activities; ii) laboratory analytical data; and iii) validated data. Data from all three pathways are entered into the project database in an electronic format in accordance with the project protocols.

Data generated during field activities are recorded using a field log book and field forms. Forms will be reviewed for completeness and accuracy by the Field Manager. Pertinent data from the field forms are entered into the project database. Hard copy field records are stored in a secure project file.

Data generated during laboratory analysis are recorded in hard copies, electronic reports in pdf format, and in electronic data deliverables (EDDs) after the samples have been analyzed. These data are then submitted for data validation. Data validation is performed in accordance with Worksheets #33, #34, #35, #36, and #37. The data validation team works with the project database manager to facilitate the uploading of the validated data into the project database in accordance with the project protocols.

Hard copies of field forms, data, and chain of custody (COC) forms are filed in a secure storage area. Laboratory data packages and reports are archived at the Geosyntec project office for a minimum of 15 years. Laboratories that generated the data archive data for 5 years unless instructed not to per project specifications. Field data are recorded manually in the project field book and uploaded to the project drive on a daily basis (i.e., scanned copies of hand-written notes).

Documentation and Records

In association with sample collection, field personnel are required to document all pertinent data, including date, time, location (coordinates), field personnel, weather conditions, instrument identification, and any other factors that may affect data quality. COC procedures in Worksheet #27 are followed for all samples. Hardcopy data (e.g., field note books; photos; hard copies of COC forms; and other items) are housed at Geosyntec offices and kept in the project files.

Assessment/Audit Tasks

Review of standard operating procedures (SOPs) relating to field, data validation, and project activities is required prior to project start. Audit records of the laboratories are maintained by the laboratory and available upon request.

QAPP WORKSHEET #15: PROJECT ACTION LIMITS AND LABORATORY-SPECIFIC DETECTION/QUANTITATION LIMITS

Laboratory: Eurofins Lancaster Laboratory Environmental, Lancaster, PA
Matrix: Groundwater

Analyte	CAS Number	Project Action Limit (mg/L)	Project Quantitation Limit Goal[1] (mg/L)	Method Specific		Laboratory Specific	
				Method Detection Limit (mg/L)	Quantitation Limit (mg/L)	Method Detection Limit (mg/L)	Quantitation (Reporting) Limit (mg/L)
Perchlorate	PHCDC10C28	0.005	0.001	0.0002	0.001	0.0002	0.001
Nitrate	14797-55-8	--	0.5	0.25	0.5	0.25	0.5
Sulfate	14808-79-8	--	4.5	1.5	4.5	1.5	4.5
Orthophosphate as Phosphorous	7723-14-0	--	0.01	0.003	0.01	0.003	0.01
Total Alkalinity	--	--	5	1.7	5	1.7	5
TOC	--	--	1	0.5	1	0.5	1
TDS	--	--	20	20	60	20	60
Sulfide	18496-25-8	--	0.1	0.1	0.2	0.1	0.3
Iron (Total and Dissolved)	7439-89-6	--	0.0228	0.0228	0.1	0.0228	0.1
Methane	74-28-8	--	0.003	0.003	0.005	0.003	0.005
Ethane	74-84-0	--	0.001	0.001	0.005	0.001	0.005
Ethene	74-85-1	--	0.001	0.001	0.005	0.001	0.005

1. For each compound, the project quantitation limit goal is equal to the laboratory's quantitation limit or Reporting Limit (RL).

\- = not applicable

Acronym list

mg/L – milligrams per Liter
TDS-Total Dissolved Solids
TOC- Total Organic Carbon

QAPP WORKSHEET #15: PROJECT ACTION LIMITS AND LABORATORY-SPECIFIC DETECTION/QUANTITATION LIMITS (CONTINUED)

Laboratory: Environmental Isotope Geochemistry Laboratory: University of Delaware, Newark, DE

Matrix: Groundwater

Analyte	CAS Number	Project Action Limit	Project Quantitation Limit Goal	Method Specific		Laboratory Specific	
				Method Detection Limit	Quantitation Limit	Method Detection Limit	Quantitation (Reporting) Limit
Perchlorate	PHCDC10C28	NA[1]	NA	NA	NA	NA	NA

1. Compound Specific Isotopic Analysis sample results are reported as ratios rather than absolute values therefore there is no detection limit or project action limit. Data analysis will be dependent upon the sample results' variation from known endmember perchlorate ratios. A mixing model will be used to determine the influence of various endmembers on the samples collected and statistical significance will be used as an indicator of data usability.

QAPP WORKSHEET #17: SAMPLING DESIGN AND RATIONALE

The following section summarizes the sampling design and rationale which will serve to characterize the perchlorate plume. Perchlorate concentrations will be delineated to the 5 ppb GWQS. All investigative methods shall be consistent with generally accepted professional methods, as described in the USEPA Region II Ground Water Sampling Procedure (USEPA, 1998). The groundwater investigation will be conducted pursuant to the requirements in N.J.A.C. 7:26E-4.1 and according to the quality assurance and quality control requirements pursuant to N.J.A.C. 7:26E-2.

In 2011 and prior, groundwater samples were collected from a monitoring well network at the Site that was largely developed to monitor chlorinated VOCs (OU1). Much of the perchlorate delineation was completed using borings and groundwater screening samples which allowed the sampling plan to be adjusted to delineate the plume configuration at that time. The results of the previous sampling conducted using vertical profile borings (VPBs) are shown in the isopleth concentration figures (provided at the end of Worksheet #10) from the Site Characterization Summary Report (SCSR; TRC, June 2011). The figures show groundwater results at three depth zones: shallow (generally 15 to 50 feet bgs); intermediate (generally 55 to 85 feet bgs); and deep (generally 85 to 135 feet bgs). In the shallow zone, perchlorate impacts were limited to the Site and the area immediately downgradient of the Site. Perchlorate was present in the intermediate zone downgradient of the Site, but at relatively low concentrations. Perchlorate was present in the deep zone both near and downgradient of the Site, at higher concentrations than in the intermediate zone. The results indicate some migration of perchlorate from the on-Site source areas in the deep zone. This was likely due in part to the natural flow in groundwater but may also have been influenced by the effects of pumping wells (including wells used for remediation of OU1 and irrigation wells) which would have drawn the perchlorate deeper and further from the Site. The OU1 remediation wells were turned off on or around April 30, 2013.

Given the age of the data and because the well network may not be appropriate to evaluate the current distribution of perchlorate, an approach consisting of two phases has been developed.

- Phase 1 – advancing soil borings and collecting groundwater samples from the borings to estimate the current distribution of perchlorate in groundwater at and downgradient of the Site; and

- Phase 2 – installation of permanent monitoring to wells to confirm the perchlorate distribution, allow collection of samples to evaluate natural attenuation processes for perchlorate, and to allow long-term monitoring of perchlorate.

Phase 1

The overall approach to Phase 1 will be to (1) return to certain of the previous sampling locations to determine whether perchlorate concentrations have remained similar since 2011; and (2) to estimate the downgradient extent of perchlorate. Ten boring locations are proposed, as summarized in the following table and shown on Figure 3 of the Revised FSP OU3 SRI. The majority of the borings are on the flow path from the Site to the southwest (based on historical water level data).

Boring Location	Depth	Purpose
GWS1	80 feet	Upgradient, to establish perchlorate concentrations in groundwater entering the Site.
GWS2	120 feet	Within former area of highest concentrations on Site.
GWS3	130 feet	At Farm Parcel, downgradient of Site, where pumping wells were operated for OU1.
GWS4	120 feet	At former boring location VP-8, where highest concentrations of perchlorate were detected in the off-Site deep zone.
GWS5	140 feet	At former boring location VP-5, to establish southern (side gradient) boundary of perchlorate.
GWS6	120 feet	At former boring location VP-13A, to establish northern (side gradient) boundary of perchlorate.
GWS7	120 feet	At former boring location VP-2, where elevated levels of perchlorate were observed in intermediate and deep zones.
GWS8	120 feet	Near former boring location VP-10, to delineate downgradient edge of perchlorate.
GWS9	120 feet	On West Forest Grove Road, west of former boring location VP-10, to delineate downgradient edge of perchlorate.
GWS10	110 feet	Near former boring location VP-15A, to delineate downgradient edge of perchlorate.

Phase 2

Phase 2 will be implemented if the results of Phase 1 indicate that perchlorate is present at concentrations above its GWQS and remediation is required. Phase 2 will consist of the installation and sampling of well nests. Each well nest will contain three wells, one each in the shallow, intermediate, and deep zones.

The general approach to the Phase 2 well nest locations will be:

- Provide upgradient monitoring at the Site to understand perchlorate levels in groundwater flowing on to the Site, and to help define groundwater flow directions;

- Install well nests in areas of elevated perchlorate concentrations (which may be the same as those defined in the previous sampling, or may be different);

- Provide monitoring to define the extent perpendicular to the groundwater flow direction (likely north and south) and downgradient edge (likely southwest) of the perchlorate.

All samples will be analyzed for perchlorate using method SW-846 6850. Samples at selected new wells will be analyzed for the following parameters to evaluate potential natural attenuation processes for perchlorate:

- Total and dissolved iron;
- Nitrate;
- Sulfate;
- Sulfide;
- Orthophosphate;
- Alkalinity;
- Total organic carbon;
- Total dissolved solids; and
- Dissolved hydrocarbons (methane, ethane, and ethene).

In addition, samples may be collected for analysis compound-specific isotope analysis (CSIA) and Gene-Trac testing. The locations for these samples will be selected in conjunction with USEPA. If collected, CSIA samples will preferentially be collected at locations on the perimeter of the perchlorate plume and with perchlorate concentrations of at least 5 micrograms per liter (µg/L). Higher concentrations of perchlorate are preferred because the sampling procedure for CSIA, discussed in detail in Appendix C of the Revised FSP OU3 SRI, requires pumping a large volume of water (i.e., 2,000 liters for a well with a perchlorate concentration of 5 µg/L) through an ion exchange column at a rate of no greater than 2 liters per minute to adsorb all perchlorate to the resin within the ion exchange column. Samples will be analyzed by CSIA to determine the isotopic composition of the perchlorate, since synthetic and naturally formed perchlorate have different isotopic compositions/signatures (Sturchio et al., 2011). This may provide evidence of the source of the perchlorate, as the synthetic perchlorate likely used at the Site should have a different isotopic signature than natural perchlorate in fertilizers used at farms near the Site (ITRC, 2005; USEPA, 2014).

Gene-Trac testing may also be used to quantify key microorganisms and to determine microbial composition for the assessment of bioremediation potential. If Gene-Trac testing is used, samples will be collected at locations with the highest perchlorate concentrations during the initial sampling round. The Gene-Trac samples will be processed, frozen, and held for analysis until a remedy is selected. They will be analyzed if the selected remedy includes a bioremediation component that requires bacterial analysis.

QAPP WORKSHEET #18: SAMPLING LOCATIONS AND METHODS

See Figure 3 and Section 3 of the Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation.

QAPP WORKSHEET #19: ANALYTICAL SOP REQUIREMENTS TABLE

Laboratory: Eurofins Lancaster Laboratory Environmental, Lancaster, PA
Matrix: Groundwater

Matrix	Analytical Group	Analytical and Preparation Method	Laboratory SOP	Sample Volume/Mass per Analysis	Containers (number, size, and type)	Preservation Requirements (Chemical, temperature, light protected)	Max Holding Time
Groundwater	Alkalinity	SM 2320B-2011 or EPA 310.1	WI11475	250 mL	250 mL plastic or glass bottle	Cool, ≤6°C	14 days
	Sulfide (colorimetric)	SM4500 S2D/ EPA 376.2	WI11483	250 mL	250 mL glass bottle	Cool, ≤6°C, no headspace, NaOH, ZnAc	7 days
	Anions: Nitrate and Sulfate	EPA 300.0 or SW-846 9056	WI11626	50 mL	50 mL plastic vial	Cool, ≤6°C	28 days
	Orthophosphate as Phosphorous	EPA 365.3	WI11511	250 mL	250 mL plastic or glass bottle	Cool, ≤6°C, Filter 0.45 µ on-site	48 hours
	Total Organic Carbon	SM 5310C/EPA 415.1	WI11637	40 mL	2 x 40 mL amber glass vial	Cool, ≤6°C, H3PO4 to pH <2	28 days
	Total Dissolved Solids	SM 2540 C-2011	WI11597	250 mL	500 mL plastic or glass bottle	Cool, ≤6°C	7 days
	Methane, Ethane, Ethene	RSK175/ or SW-846 8015C or D	WI9015178	40 mL	2 x 40 mL glass vials, no headspace	HCL to pH<2; Cool, ≤6°C, no headspace	7 days
	Metals (Total and Dissolved Iron)	EPA 200.8	WI11933	250 mL	250 mL plastic	Field filter 0.45 µ (dissolved); HNO3 to pH <2 (total and dissolved)	6 months
	Perchlorate	SW-846 6850	WI9989	40 mL	40 mL glass vial	Cool, ≤6°C	28 days

Acronym list
mL – milliliter
SOP – Standard Operating Procedure

QAPP WORKSHEET #19: ANALYTICAL SOP REQUIREMENTS TABLE (CONTINUED)

Laboratory: Environmental Isotope Geochemistry Laboratory: University of Delaware, Newark, DE
Matrix: Groundwater

Matrix	Analytical Group	Analytical and Preparation Method	SOP	Sample Volume/Mass per Analysis (mg)[2]	Containers (number, size, and type)	Preservation Requirements (Chemical, temperature, light protected	Max Holding Time
Groundwater	CSIA	CSIA	ESTCP: Guidance Manual for Forensic Analysis of Perchlorate in Groundwater using Chlorine and Oxygen Isotopic Analyses[1]	10	1 ion exchange column (1.25" by 3")	Filtered, none, 2-4º C	NA

1. This guidance document is provided in the Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation, Appendix C. There is no SOP for CSIA sampling, protocols will be based on the provided guidance document with any updates required.
2. Volume of sample water purged will vary by well, sample mass is listed as mg of total perchlorate. The sample mass will be collected by pumping the required volume of water (i.e., 2000 L for a well with a perchlorate concentration of 5 µg/L) through the ion exchange column at a rate of no greater than 2L/min to adsorb all perchlorate to the resin within the ion exchange column.

Acronym list

CSIA – Compound-Specific Isotope Analysis
ESTCP - Environmental Security Technology Certification Program
SOP – Standard Operating Procedure
mg - milligram

QAPP WORKSHEET #20: FIELD QC SUMMARY

Laboratory: Eurofins Lancaster Laboratory Environmental, Lancaster, PA
Matrix: Groundwater

Matrix	Analytical Group	Conc. Level	Analytical and Preparation SOP Reference	No. of Field Duplicate Pairs	No. of MS/MSD	No. of Field Blanks	No. of Equipment Blanks	No. of Trip Blanks
Groundwater	Alkalinity	Low	SM 2320B-2011 or EPA 310.1	1 per 20 samples	1 per 20 samples	1 per day or 1 per 20 samples whichever is greater	1 per day or 1 per 20 samples whichever is greater	N/A
	Sulfide (colorimetric)	Low	SM4500 S2D/ EPA 376.2	1 per 20 samples	1 per 20 samples	1 per day or 1 per 20 samples whichever is greater	1 per day or 1 per 20 samples whichever is greater	N/A
	Anions: Nitrate and Sulfate	Low	EPA 300.0 or SW-846 9056	1 per 20 samples	1 per 20 samples	1 per day or 1 per 20 samples whichever is greater	1 per day or 1 per 20 samples whichever is greater	N/A
	Orthophosphate as Phosphorous	Low	EPA 365.3	1 per 20 samples	1 per 20 samples	1 per day or 1 per 20 samples whichever is greater	1 per day or 1 per 20 samples whichever is greater	N/A
	Total Organic Carbon	Low	SM 5310C/EPA 415.1	1 per 20 samples	1 per 20 samples	1 per day or 1 per 20 samples whichever is greater	1 per day or 1 per 20 samples whichever is greater	N/A
	Total Dissolved Solids	Low	SM 2540 C-2011	1 per 20 samples	1 per 20 samples	1 per day or 1 per 20 samples whichever is greater	1 per day or 1 per 20 samples whichever is greater	N/A

Acronym list
MS/MSD - Matrix Spike/Matrix Spike Duplicate

QAPP WORKSHEET #20: FIELD QC SUMMARY (CONTINUED)

Laboratory: Eurofins Lancaster Laboratory Environmental, Lancaster, PA
Matrix: Groundwater

Matrix	Analytical Group	Conc. Level	Analytical and Preparation SOP Reference	No. of Field Duplicate Pairs	No. of MS/MSD	No. of Field Blanks	No. of Equipment Blanks	No. of Trip Blanks
Groundwater	Dissolved Hydrocarbons (Methane, Ethane, and Ethene)	Low	RSK175/ or SW-846 8015C or D	1 per 20 samples	1 per 20 samples	1 per day or 1 per 20 samples whichever is greater	1 per day or 1 per 20 samples whichever is greater	1 per cooler
	Metals (Total and Dissolved Iron)	Low	EPA 200.8	1 per 20 samples	1 per 20 samples	1 per day or 1 per 20 samples whichever is greater	1 per day or 1 per 20 samples whichever is greater	N/A
	Perchlorate	Low	SW-846 6850	1 per 20 samples	1 per 20 samples	1 per day or 1 per 20 samples whichever is greater	1 per day or 1 per 20 samples whichever is greater	N/A

Acronym list
MS/MSD - Matrix Spike/Matrix Spike Duplicate

QAPP WORKSHEET #20: FIELD QC SUMMARY (CONTINUED)

Laboratory: Environmental Isotope Geochemistry Laboratory: University of Delaware, Newark, DE
Matrix: Groundwater

Matrix	Analytical Group	Conc. Level	Analytical and Preparation SOP Reference	No. of Field Duplicate Pairs	No. of MS/MSD	No. of Field Blanks	No. of Equipment Blanks	No. of Trip Blanks
Groundwater	CSIA	Low	ESTCP: Guidance Manual for Forensic Analysis of Perchlorate in Groundwater using Chlorine and Oxygen Isotopic Analyses[1]	1 per 10 samples	N/A	N/A	N/A	N/A

1. This guidance document is provided in the Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation, Appendix C. There is no SOP for CSIA sampling, field protocols will be based on the Environmental Isotope Geochemistry Laboratory Instructions for Perchlorate Collection Field Columns (Appendix C of the Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation) with any updates required.

Acronym list

CSIA – Compound-Specific Isotope Analysis
ESTCP - Environmental Security Technology Certification Program
MS/MSD - Matrix Spike/Matrix Spike Duplicate
SOP – Standard Operating Procedure

QAPP WORKSHEET #21: FIELD SOPS

SOP Number	Title, Revision Date and / or Number	Originating Organization	Equipment Type	Modified for Project Work? (Y/N)	Comments
SOP 100	Water Level Measurement Procedures, February 2007	Geosyntec Consultants	Not applicable	N	-
SOP 101	Field Documentation, Sample Designation, Custody and Handling Procedures, November 2014	Geosyntec Consultants	Not applicable	N	-
SOP 104	Management and Disposal of Investigation Derived Waste, November 2014	Geosyntec Consultants	Applies to purge water, section 2	N	-
SOP 106	Water and NAPL Level Measurement Procedures, November 2014	Geosyntec Consultants	Not applicable	N	-
SOP 107	Soil Description: Visual – Manual Procedure of the Unified Classification System, November 2014	Geosyntec Consultants	Not applicable	N	-
SOP 108	Collection of Groundwater Samples, November 2014	Geosyntec Consultants	Samples will be collected by bailer (Phase 1) and pump (Phase 2)	N	-
SOP (Cascade)	Groundwater Sampling with Push-Ahead™ Tool	Cascade Drilling and Technical Services	Not applicable	N	-
SOG NJ1	Dissolved Oxygen (DO) Calibration, Revision 1, April 2018	Geosyntec Consultants	Not applicable	N	-
SOG NJ2	Specific Conductance Calibration, Revision 1, April 2018	Geosyntec Consultants	Not applicable	N	-

SOG NJ3	**Temperature Calibration, Revision 1, April 2018**	**Geosyntec Consultants**	**Not applicable**	**N**	**-**
SOG NJ4	**Turbidity Calibration, revision 1, April 2018**	**Geosyntec Consultants**	**Not applicable**	**N**	**-**
SOG NJ5	**pH Calibration, revision 1, April 2018**	**Geosyntec Consultants**	**Not applicable**	**N**	**-**

1. **The above SOPs are provided in Appendix A of the Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation.**

Acronym list

SOP – Standard Operating Procedure
SOG – Standard Operating Guideline

QAPP WORKSHEET #22: FIELD EQUIPMENT CALIBRATION, MAINTENANCE, TESTING, AND INSPECTION

YSI 650MDS with YSI 600 XL/XLM, 6920, or 6820 sonde; YSI 556; or equivalent

Parameters: YSIs will be utilized during groundwater sampling and monitoring to analyze for dissolved oxygen, specific conductivity, temperature, pH, and oxidation/reduction potential.

Calibration: Parameter-specific calibration solutions will be used to calibrate individual sensors. Calibration parameters will include:

- Conductivity: Single-point calibration
- Turbidity: Three-point calibration
- Dissolved oxygen: Single-point calibration (100% saturation in air)
- Temperature: Factory calibrated (temperatures of all calibration standards should be recorded during calibration)
- pH: Three-point calibration (including 7.0)
- Oxidation/Reduction potential (ORP): Single-point calibration

Calibration will be performed in accordance with instrument instruction manuals. Ensure that calibration solutions are not past the expiration date prior to calibration. Expired solutions will not be used to calibrate instruments. Water depth does not require calibration.

Maintenance: see below SOPs.

Inspection: The YSI Sonde should be inspected throughout the day during real-time use to ensure proper function. Sensors should be inspected for cleanliness and integrity. Cables should be inspected for cuts and abrasions and display units should be inspected for proper function. All inspection activities should be documented, as appropriate.

Frequency: Calibration should be done at the beginning of the day, and whenever readings are outside of acceptable limits (see below). Inspection should be done during testing, calibration or whenever damage to the YSI may have occurred. A final calibration check will be recorded at the end of the day.

Acceptance:

Parameter	Units	Criteria
pH	pH units	± 0.3 pH units
ORP	mV	± 10 mV
Temperature	°C	NA
Conductivity	µS/cm	± 5% of standard or ± 10 µS/cm (whichever is greater)
Dissolved Oxygen	mg/L	± 0.5 mg/L of sat. value

Acronym list

SOP – Standard Operating Procedure

QAPP WORKSHEET #22: FIELD EQUIPMENT CALIBRATION, MAINTENANCE, TESTING, AND INSPECTION (CONTINUED)

YSI 650MDS with YSI 600 XL/XLM, 6920, or 6820 sonde; YSI 556; or equivalent (continued)
Corrective Action: The initial corrective action for parameters falling outside of the acceptable accuracy range will be inspection of deficient sensors for dirt, deposits, or damage followed by recalibration of affected sensors. YSI recalibration should be conducted whenever readings fall outside of acceptance criteria. Some minor repairs or replacements, such as replacement of dissolved oxygen sensor membranes, may be done by field team members on site, while other repairs will require a professional repair service. Replacement batteries should be kept on hand for prompt replacement if battery levels are observed to be low or error codes indicate low batteries. Separate batteries are required for the YSI Sonde and digital display, and both should be kept on hand. If midday or end-of-day checks identify results outside acceptance criteria, readings taken during the portion of the day when results may have been inaccurate should be noted and qualified.
Responsible Person: Field Team Leader
SOP Reference: SOG NJ1, SOG NJ2, SOG NJ3, SOG NJ5

Turbidity Meter
Parameters: The groundwater sampling and monitoring will utilize turbidity meters to analyze for turbidity.
Calibration: Calibration will be performed using a three-point calibration curve in accordance with instrument instruction manuals and SOG NJ4. Ensure that calibration solutions are not past the expiration date prior to calibration. Expired solutions will not be used to calibrate instruments.
Maintenance: see SOG NJ4
Inspection: Equipment shall be inspected for defects upon receipt, prior to calibration, and periodically during sampling.
Frequency: Calibration is performed at the beginning of the day. Calibration checks will be done after initial calibration and at the end of the day. Testing and inspection should be done if there are any incidents which may cause damage to the unit.
Acceptance: see SOG NJ4
Corrective Action: If there is any indication that the equipment is broken or malfunctioning, it will be replaced or returned to the rental company for replacement.

Acronym list

SOG – Standard Operating Guideline

QAPP WORKSHEET #22: FIELD EQUIPMENT CALIBRATION, MAINTENANCE, TESTING, AND INSPECTION (CONTINUED)

MINI RAE 2000 and 3000
Parameters: The mini RAE 2000 is a photoionization detector (PID) that generally measures VOCs such as isobutylene, hexane, xylene, benzene, styrene, toluene, and vinyl chloride, but can be calibrated to identify other volatile gases. The instrument will be used to evaluate work areas for health and safety and PPE requirements.
Calibration: Calibration should be performed at the beginning of each work day. The calibration will be a two-point curve including a “fresh air” calibration at 0.0 ppm and a span gas calibration at 100 ppm. Calibration procedures are outlined in the MiniRAE instruction manual. A correction factor may need to be used for certain gases (see MiniRAE user manual for more information). Lower and upper alarm limits should match criteria outlined in the Health and Safety Plan for PPE upgrade conditions (generally 5 ppm and 50 ppm, sustained). Calibration should be documented daily. Ensure that calibration span gas has not expired. Expired calibration gases should not be used to calibrate the PID.
Maintenance: Battery should be charged daily and will require replacing in the field when it can no longer recharge. PIDs are sensitive to moisture; therefore, a moisture/particulate filter should always be used, fitted on the PID intake. If the lamp or lamp housing becomes wet or soiled, these areas will require cleaning in accordance with the MiniRAE user manual. Additionally, filters will require replacement after use. Indications that a filter, particulate or vapor, requires replacement include: visible particulate matter, inability for unit to zero, tearing, or obstruction of flow (audible indication of pump straining). The PID digital display should be kept from overexposure to water and sunlight to maximize display longevity. Common replacement parts that will be immediately available during PID use are listed below: • Vapor filters; • Particulate filters; • AA batteries; and • Replacement lamps. All maintenance and corrective action activities should be appropriately documented on field forms and/or in field logbooks.

QAPP WORKSHEET #23: ANALYTICAL SOPS

Reference Number	Title	Definitive or Screening Data	Analytical Group	Instrument	Organization Performing Analysis	Modified for Project Work? (Y/N)
WI11475	*Multi-Parameters in Solids and Waters by Man-Tech Multi-Parameter System Rev 11; effective 3/21/19*	Definitive	Water	Man-Tech Multi-Parameter System	Eurofins Lancaster Laboratories Environmental	N
WI11483	*Colorimetric Sulfide in Waters (#0230), Sulfide as H2S (#10293 Calculation), Dissolved Sulfide in Water (#10499) by 4500-S2 B/C/D-2011, 4500-S2 F-2011, or EPA 376.2, Rev 17, effective 3/15/18*	Definitive	Water	UV Spec	Eurofins Lancaster Laboratories Environmental	N
QA-SOP11880	*Balance, Syringe, Pipette, and Labware Verification, Rev 9, effective 07/02/18*	Definitive	Maintenance	Balance	Eurofins Lancaster Laboratories Environmental	N
WI11519	*pH Probes and Meters, Rev 13, effective 10/13/16*	Definitive	Water and Solid	pH Meter	Eurofins Lancaster Laboratories Environmental	N
WI11626	*Determination of Inorganic anions by Ion Chromatography in Waters and Soil by EPA 300.0, SW 846 9056, and SW 846 9056A, Rev 22, effective 12/24/18*	Definitive	Water and Solid	IC	Eurofins Lancaster Laboratories Environmental	N
WI11511	*Orthophosphate (Colorimetric) by EPA 365.3 in Waters, Rev 12, effective 5/09/18*	Definitive	Water	UV Spectrophotometer	Eurofins Lancaster Laboratories Environmental	N

QAPP WORKSHEET #23: ANALYTICAL SOPS (CONTINUED)

Reference Number	Title	Definitive or Screening Data	Analytical Group	Instrument	Organization Performing Analysis	Modified for Project Work? (Y/N)
WI11637	*Determination of Total Organic Carbon, Dissolved Organic Carbon, and Inorganic Carbon in Water and Wastewater, Rev 16, effective 9/25/18*	Definitive	Water	TOC Analyzer	Eurofins Lancaster Laboratories Environmental	N
WI11598	*Total Dissolved Solids (TDS)(Gravimetric) by 2540C-2011 or EPA 160.1 in Waters and Wastewaters, Rev 16, effective 4/08/19*	Definitive	Water	NA	Eurofins Lancaster Laboratories Environmental	N
WI9796	*Volatile Hydrocarbons in Water by Method RSK-175 Modified and SW-846 8015 Using Headspace Sampling Techniques and GC-FID, Rev 18, effective 12/05/18*	Definitive	Dissolved Hydrocarbons	GC	Eurofins Lancaster Laboratories Environmental	N
WI9689	*Maintenance and Troubleshooting Procedures for GC/FID Instrumentation, Rev 8, effective 1/16/2015*	N/A	Maintenance	N/A	Eurofins Lancaster Laboratories Environmental	N
WI11933	*Metals by Inductively Coupled Plasma Mass Spectrometry for SW-846 Methods 6020/6020A/6020B (aqueous, solid, tissue), and EPA 200.8 (aqueous), Rev 8, effective 09/25/18*	Definitive	Solid, liquid, tissues Metals	ICP/MS	Eurofins Lancaster Laboratories Environmental	N
WI9989	*Perchlorate by Method 6850 in Waters and Solids by LC/MS/MS, Rev 13, effective 03/22/19*	Definitive	Perchlorate by LC/MS/MS	LC/MS/MS	Eurofins Lancaster Laboratories Environmental	N

QAPP WORKSHEET #23: ANALYTICAL SOPS (CONTINUED)

Reference Number	Title	Definitive or Screening Data	Analytical Group	Instrument	Organization Performing Analysis	Modified for Project Work? (Y/N)
WI10008	*Preventive and corrective HPLC Maintenance for the Pesticide Residue Analysis Department, Rev 6, effective 5/17/13*	NA	Maintenance	NA	Eurofins Lancaster Laboratories Environmental	N
ESTCP Project ER-200509 (Guidance Document)	*Guidance Manual for Forensic Analysis of Perchlorate in Groundwater using Chlorine and Oxygen Isotopic Analyses*[1]	Definitive	Waters	IRMS	Environmental Isotope Geochemistry Laboratory: University of Delaware	TBD

1. This guidance document is provided in the Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation, Appendix C. There is no SOP for CSIA sampling, protocols will be based on the provided guidance document with any updates required.
2. Potential modifications will be decided based on first round of sampling.

Acronym list

GC – gas chromatography
IC – ion chromatography
IRMS – isotope-ratio mass spectrometry
LC – liquid chromatograph
MS – mass spectrometer
TOC – total organic carbon

QAPP WORKSHEET #24: ANALYTICAL INSTRUMENT CALIBRATION

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA

Parameter	Calibration Procedure/Range	Frequency of Calibration	Acceptance Criteria	Corrective Action (CA)	Person Responsible for CA	SOP Reference
pH electrode: Alkalinity	Calibration using at least 3 points, sloped with pH 4, 7, and 10 buffers	Daily	percent slope between 92% and 102%	Correct the problem and recalibrate	ELLE Analyst	WI11475
	CCV Standard	After each calibration, every 10 samples, and end of batch	±10% D	Correct the problem, recalibrate and reanalyze affected samples		
Sulfide	Calibration using at least 5 points ranging from 0.10 to 2.0 mg/l	Every 3 months or when a new reagent is prepared	Correlation coefficient must be ≥0.995	Correct the problem and recalibrate	ELLE Analyst	WI11483
	CCV Standard	Beginning of each batch, every 10 samples, and end of batch	±10% D	Correct the problem, recalibrate and reanalyze affected samples		
IC Anions 300.0 or SW-846 9056	Initial calibration with a minimum of 5 points with a concentration span of 15x or 30x depending on the analyte	Every 60 days or when CCV fails	r >0.995; Level 1 standard must recover ≥50% of the true value	Perform more aggressive instrument maintenance and recalibrate	ELLE Analyst	WI11626
	ICB	After each initial calibration	No analytes detected > MDL	Correct problem and reanalyze the ICB. Recalibrate if needed.		
	ICV	After each initial calibration	Within +/- 10% of the nominal concentration	If ICV fails again do system maintenance and recalibrate.		
	CCV	Every 10 injections	Within +/- 10% of the nominal concentration	Recalibrate; reanalyze affected samples		
	CCB	Every 10 injections	No analytes detected > MDL	Recalibrate; reanalyze affected samples		

QAPP WORKSHEET #24: ANALYTICAL INSTRUMENT CALIBRATION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA

Parameter	Calibration Procedure/Range	Frequency of Calibration	Acceptance Criteria	Corrective Action (CA)	Person Responsible for CA	SOP Reference
UV Spectrophotometer	Initial Calibration with a minimum 5 points ranging from 0.1 mg/L to 0.8 mg/L.	Quarterly	Correlation Coefficient of >0.995	Recalibrate, perform instrument maintenance if calibration cannot conform to criteria, recalibrate	ELLE Analyst	WI11511, WI11495, WI11537
	ICV Standard	After each ICAL	±10% D	Reanalyze the ICV. If ICV fails again do system maintenance and recalibrate.		
	CCV Standard	Every 10 samples	±10% D	Reanalyze affected samples		
TOC Analyzer: TOC, DOC, & TIC in Water	Initial calibration with a minimum 6 points ranging from 1.0 ppm to 100 ppm	Monthly or after continuing calibration fails	$r^2 \geq 0.995$	Perform more aggressive instrument maintenance and recalibrate	ELLE Analyst	WI11637, WI11682
	ICB Standard	After each initial calibration	No analytes detected > LOQ	Perform more aggressive instrument maintenance and recalibrate		
	ICV Standard	After each initial calibration	Within +/- 10% of the nominal concentration	Reanalyze the ICV. If ICV fails again do system maintenance and recalibrate.		
	Total Inorganic Check Standard	Daily	Within +/- 20% of the nominal concentration	All affected samples are reanalyzed		
	CCV Standard	If instrument is idle > 4 hours, after every 10 field samples, and at the end of the sequence	Within +/- 10% of the nominal concentration	All affected samples are reanalyzed		
	CCB Standard	If instrument is idle > 4 hours, after every 10 field samples, and at the end of the sequence	No analytes detected > LOQ	All affected samples are reanalyzed		
Total Dissolved Solids	NA	NA	NA	NA	ELLE Analyst	WI11598

QAPP WORKSHEET #24: ANALYTICAL INSTRUMENT CALIBRATION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA

Parameter	Calibration Procedure/Range	Frequency of Calibration	Acceptance Criteria	Corrective Action (CA)	Person Responsible for CA	SOP Reference
Gas Chromatography Dissolved Hydrocarbons	Initial calibration with 6 points ranging from 2 ppb to 500 ppb depending on the compound	After continuing calibration fails	%RSD for ICAL ≤20%, linear $r^2 \geq 0.99$	Perform more aggressive instrument maintenance and recalibrate	ELLE Analyst	WI9796
	MDL Standard	After each initial calibration	All compounds must be detected	Repeat initial calibration procedure prior to analyzing samples. Repeat maintenance if needed.		
	ICV Standard	After each initial calibration	Target compounds +/- 15% of the nominal concentration and within established retention time windows	Reanalyze the ICV. If ICV fails again do system maintenance and recalibrate.		
	CCV Standard	Prior to sample analysis, after every 10 field samples, and at the end of the sequence.	For RSK-175: Target compounds +/- 15% of the nominal concentration. For SW-846 8015C/D: Target compounds +/- 20% of the nominal concentration.	All samples since acceptable CCV must be reanalyzed. If the CCV fails high, any associated samples that are ND can be reported.		

QAPP WORKSHEET #24: ANALYTICAL INSTRUMENT CALIBRATION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA

Parameter	Calibration Procedure/Range	Frequency of Calibration	Acceptance Criteria	Corrective Action (CA)	Person Responsible for CA	SOP Reference
ICP/MS: 200.8	Tuning	Daily	No AMU diff. of >0.1 P.W. ≥0.64 and ≥0.66 (Elan 9000) or P.W. <0.9 at 10% height (Agilent); %RSD <5 for masses used for tuning	Perform mass calibration for AMU. Adjust mass calibration for P.W.	ELLE Analyst	WI11933
	Initial Calibration consists of Blank and 1 point: 0 and 10,000 ppb for Al, Ca, Fe, Mg, K, Na; 0 and 1,000 ppb for As, Ba, Cr, Co, Cu, Mn, Ni, Ti, V, Zn; 0 and 100 ppb for Sb, Be, Cd, Pb. Mo, Se, Ag, Sr, Tl, Sn	Each new run	Passing ICV and ICB	Recalibrate, perform instrument maintenance if calibration cannot conform to criteria, recalibrate		
	ICV	After each calibration	±10% of true value	Reanalyze		
	ICB	Immediately after the ICV	Less than 3x IDL	Positive result: accept sample results >10X the ICB or < 1/2 RL. Negative result: accept results >10x ICB. All other samples must be reanalyzed with compliant ICB		
	CCV	Immediately after the ICSAB and every 10 samples	±10% of true value	If the CCV is out of specification and the result is not < - LOQ, accept results that report as non-detect for the affected analyte(s). Results for the affected analyte(s) ≥ to the reporting limit must not be reported (reanalyze).		

QAPP WORKSHEET #24: ANALYTICAL INSTRUMENT CALIBRATION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA

Parameter	Calibration Procedure/Range	Frequency of Calibration	Acceptance Criteria	Corrective Action (CA)	Person Responsible for CA	SOP Reference
ICP/MS: 200.8 (continued)	CCB	Immediately after the CCV and every 10 samples	Less than 3x IDL	Positive result: accept sample results >10X the ICB or < 1/2 RL. Negative result: accept results >10x ICB. All other samples must be reanalyzed with compliant CCB	ELLE Analyst	WI11933
	Interference Check Sample	At the beginning of each run immediately following the LLC	± 20% of the true value for each analyte	Recalibrate		
	Low Level Check (LLC)	Beginning of each sequence and before the interference check samples	± 50% of the true value. Not applicable if sample concentrations are >10x the true value of the LLC.	Reanalyze the sample		
	Linear Range	Quarterly	±10% of true value	Samples > 90% of the linear range must be reanalyzed as a dilution		
HPLC/MS/MS Perchlorate 6850	Tuning	Required prior to analysis and at end of sequence.	The mass axis tolerances for unit width are 0.10, for wide width they are 0.60, for the widest width they are 1.25.	Clean spray chamber. If needed, perform maintenance on the MS and then retune	ELLE Analyst	WI9989
	Initial calibration with a minimum 5 points. Ranges from a standard at or near the reporting limits through 20x the first level	After continuing calibration fails	correlation coefficient ≥0.995.	Perform more aggressive instrument maintenance and recalibrate		
	MDL Standard	After each initial calibration	Perchlorate must be detected	Repeat initial calibration procedure prior to analyzing samples. Repeat maintenance if needed.		

QAPP WORKSHEET #24: ANALYTICAL INSTRUMENT CALIBRATION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA

Parameter	Calibration Procedure/Range	Frequency of Calibration	Acceptance Criteria	Corrective Action (CA)	Person Responsible for CA	SOP Reference
HPLC/MS/MS Perchlorate 6850 (continued)	ICV Standard	After each initial calibration	Within +/-15% of the nominal concentration and within established retention time windows	Reanalyze the ICV and samples associated with the non-compliant ICV. If ICV fails again do system maintenance, recalibrate, and reanalyze samples.	ELLE Analyst	WI9989
	CCV Standard	Prior to sample analysis, after every 10 field samples, and at the end of the sequence. Alternate between low- and mid-range concentrations	Within ±15% for mid-range and ±50% for low-range of the nominal concentration and within established retention time windows	All samples since acceptable CCV must be reanalyzed. If the CCV fails high, any associated samples that are ND can be reported.		

QAPP WORKSHEET #24: ANALYTICAL INSTRUMENT CALIBRATION (CONTINUED)

Laboratory: Environmental Isotope Geochemistry Laboratory: University of Delaware, Newark, DE

Parameter	Calibration Procedure/Range	Frequency of Calibration	Acceptance Criteria	Corrective Action (CA)	Person Responsible for CA	SOP Reference
Isotope Ratio Mass Spectrometer	CCV Standard	Prior to sample analysis, after every 4 field samples, and at the end of the sequence.	Within analytical uncertainty (typically ±0.5‰)	Reanalyze the CCV and associated samples.	University of Delaware Analyst	N/A
	ICV Standard (reference gas, O_2 and CH_3Cl)	After initial calibration and at least three times per day of analysis	Within analytical uncertainty (typically ±0.5‰)	Reanalyze the ICV		

Acronym list

AMU - Atomic Mass Unit
CCB - Continuing Calibration Blank
CCV - Continuing Calibration Verification
ICB - Initial Calibration Blank
ICP - Inductively Coupled Plasma
ICV - Initial Calibration Verification
IDL – Instrument Detection Limit
LLC – Low Level Check
LOQ – Limit of Quantitation
MDL – Method Detection Limit
mg/L – milligrams per Liter
MS – Mass Spectrometer
ND – None Detected
SOP – Standard Operating Procedure

QAPP WORKSHEET #25: ANALYTICAL INSTRUMENT AND EQUIPMENT MAINTENANCE, TESTING, AND INSPECTION

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA

Instrument/ Equipment	Maintenance Activity	Testing Activity	Inspection Activity	Frequency	Acceptance Criteria	Corrective Action	Responsible Person	SOP Reference
pH/ISE Meter	As needed replacement of components	Calibration checks	Visual inspection of components	As needed maintenance/calibration checks every 10 injections	90-110% for calibration checks	Recalibration	ELLE Analyst	WI11519
Analytical balance	Assure the balance is in a vibration-free area, is level, and the interior housing is clean.	Verification with ASTM certified weights	Visual inspection and weight verification	Each day of use	The reading must be ±0.1% or ±0.5mg, whichever is greater.	1) verify cleanliness of weights 2) remove balance from service and place a call to service firm 3) management must evaluate data generated since last acceptable reading to determine any potential impacts to data quality	ELLE analyst	QA-SOP-11880
Analytical balance	Annual calibration and maintenance	Annual calibration and maintenance	Annual calibration and maintenance	Annual	As per vendor's specifications in compliance with ISO certification	As per vendor's specifications in compliance with ISO certification	Professional calibration vendor (ISO 17025 certified)	QA-SOP-11880
IC	As needed replacement of components	Calibration checks	Visual inspection of components	As needed maintenance/calibration checks every 10 injections	90-110% for calibration checks (95-105% for method 218.6)	Recalibration	ELLE Analyst	WI11625

QAPP WORKSHEET #25: ANALYTICAL INSTRUMENT AND EQUIPMENT MAINTENANCE, TESTING, AND INSPECTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA

Instrument/ Equipment	Maintenance Activity	Testing Activity	Inspection Activity	Frequency	Acceptance Criteria	Corrective Action	Responsible Person	SOP Reference
Total Organic Carbon Analyzer	As needed replacement of components	Calibration checks	Visual inspection of components	As needed maintenance/calibration checks every 10 injections	90-110% for calibration checks	Recalibration	ELLE Analyst	WI11637
HP5890, HP6890, or Agilent 7890 Gas Chromatograph with Flame Ionization Detector	Injection port maintenance; Column; FID maintenance	Continuing Calibration Check	Visual Inspection	As Needed	Initial Calibration within Specifications	Perform Maintenance again; re- calibrate if necessary	ELLE analyst	WI9689
Agilent 7500 CE	As needed replacement of components	Calibration checks	Visual inspection of components	As needed maintenance/ calibration checks every 10 injections	90-110% for the calibration checks	Recalibration	ELLE Analyst	WI11933
Agilent 1200 or HP 100 series LC/MS/MS or equivalent	Injection port maintenance; MS/MS detector maintenance	Calibration Check All analytes within +/- 15% of the nominal concentration and within established retention time windows	Visual Inspection	As needed	Initial calibration after maintenance is within specifications	Perform maintenance again	ELLE Analyst	WI10008

QAPP WORKSHEET #25: ANALYTICAL INSTRUMENT AND EQUIPMENT MAINTENANCE, TESTING, AND INSPECTION (CONTINUED)

Laboratory: Environmental Isotope Geochemistry Laboratory: University of Delaware, Newark, DE

Instrument/ Equipment	Maintenance Activity	Testing Activity	Inspection Activity	Frequency	Acceptance Criteria	Corrective Action	Responsible Person	SOP Reference
Isotope Ratio Mass Spectrometer	Disassemble, clean, and reassemble ion source	Cleaning	Visual inspection of components	Annual	Initial calibration after maintenance is within specifications	Perform maintenance again	University of Delaware Analyst	N/A

Acronym list

ASTM- American Society for Testing and Materials
FID - Flame Ionization Detector
IC – Ion Chromatography
MS – Mass Spectrometer
SOP – Standard Operating Procedures

QAPP WORKSHEET #26: SAMPLE HANDLING, CUSTODY, AND DISPOSAL

Sample Collection, Packaging, and Shipment
Sample Collection (Personnel/Organization): Field Manager, Geosyntec
Sample Packaging (Personnel/Organization): Field Manager, Geosyntec
Coordination of Shipment (Personnel/Organization): Field Manager, Geosyntec
Type of Shipment/Carrier: Courier or overnight shipping

Sample Receipt and Analysis
Sample Receipt (Personnel/Organization): Sample Receiving Personnel, Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Sample Custody and Storage (Personnel/Organization): Sample Receiving Personnel, Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Sample Preparation (Personnel/Organization): Sample Receiving Personnel, Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Sample Determinative Analysis (Personnel/Organization): Sample Receiving Personnel, Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Sample Disposal
Personnel/Organization: Sample Receiving Personnel, Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Analysis: Field Samples are stored for 30 days after submittal of the completed data package.

QAPP WORKSHEET #26: SAMPLE HANDLING, CUSTODY, AND DISPOSAL (CONTINUED)

Sample Receipt and Analysis[1]
Sample Receipt (Personnel/Organization): Andrew Jackson, Civil and Environmental Engineering, Texas Tech University, 911 Boston, Box 41023, Lubbock, TX 79409-1023/ Sample Receiving Personnel, Environmental Isotope Geochemistry Laboratory: University of Delaware, Newark, DE
Sample Custody and Storage (Personnel/Organization): Andrew Jackson, Civil and Environmental Engineering, Texas Tech University, 911 Boston, Box 41023, Lubbock, TX 79409-1023/ Sample Receiving Personnel, Environmental Isotope Geochemistry Laboratory: University of Delaware, Newark, DE
Sample Preparation (Personnel/Organization): Andrew Jackson, Civil and Environmental Engineering, Texas Tech University, 911 Boston, Box 41023, Lubbock, TX 79409-1023/ Sample Receiving Personnel, Environmental Isotope Geochemistry Laboratory: University of Delaware, Newark, DE
Sample Determinative Analysis (Personnel/Organization): Andrew Jackson, Civil and Environmental Engineering, Texas Tech University, 911 Boston, Box 41023, Lubbock, TX 79409-1023/ Neil Sturchio, Environmental Isotope Geochemistry Laboratory: University of Delaware, Newark, DE
Sample Disposal
Personnel/Organization: Sample Receiving Personnel, Environmental Isotope Geochemistry Laboratory: University of Delaware, Newark, DE,
Analysis: Field Samples are stored for 30 days after submittal of the completed data package.

1. Extractions and Purification of CSIA samples occur at Texas Tech University Laboratory and Isotope Analyses are performed at the University of Delaware.

QAPP WORKSHEET #27: SAMPLE CUSTODY REQUIREMENTS

Chain-of-Custody Procedures:

Field sample personnel will use standard sample custody procedures to maintain and document sample integrity during collection, transportation, storage, and analysis. A sample will be considered to be in custody if one of the following statements applies:

- It is in a person's physical possession or view;
- It is in a secure area with restricted access; or
- It is placed in a container and secured with an official seal so that the sample cannot be reached without breaking the seal.

Chain of custody procedures provide an accurate written record that traces the possession of individual samples from the time of collection in the field to the time of acceptance at the laboratory. The chain of custody record will also be used to document the samples collected and the analyses requested. Information that the field personnel will record on the chain of custody record includes:

- Project name and number;
- Sampling location;
- Name of sampler;
- Destination of samples (laboratory name);
- Sample identification number;
- Date and time of collection;
- Number of containers filled;
- Analysis requested;
- Preservatives used (if applicable);
- Filtering (if applicable);
- Sample designation (grab or composite);
- Signatures of individuals involved in custody transfer, including the date and time of transfer; and
- Project contact and email address.

Field personnel will sign chain of custody records that are initiated in the field, and the air bill number will be recorded if applicable. The record will be placed in a waterproof plastic bag and taped to the inside of the shipping container used to transport the samples. Signed air bills will serve as evidence of custody transfer between field personnel and the courier, and between the courier and the laboratory. Copies of the chain of custody record and the air bill, if applicable, will be retained and filed by field personnel before the containers are shipped.

Field Sample Custody Procedures (sample collection, packaging, shipment, and delivery to laboratory):

The following procedures will be implemented when samples collected during this project are shipped via laboratory courier or overnight shipping service:

- Confirm that sample labels are securely affixed to sample containers.
- Check the caps on the sample containers to confirm that they are properly sealed.

QAPP WORKSHEET #27: SAMPLE CUSTODY REQUIREMENTS (CONTINUED)

- Complete the COC form with the required sampling information and confirm that the recorded information matches the sample labels. The appropriate personnel will sign and date the COC form to document the sample custody transfer.
- Wrap sample containers in bubble wrap or other cushioning material.
- Place cushioning material at the bottom of the cooler.
- Place the sealed sample containers and a temperature blank in the cooler.
- Place a sufficient amount of wet ice in the cooler to maintain a sample temperature of <6°C.
- Fill the remaining space in the cooler with cushioning material.

The following procedures will be implemented only when shipping via an overnight shipping service.

- Place the COC forms in plastic bags and seal. Tape the forms to the inside of the appropriate cooler lid.
- Close the cooler lid and secure with tape.
- Wrap tape around both ends of the cooler and attach custody seals to the cooler and cover with clear protective tape.
- Mark the cooler on the outside with the following information: Shipping address, return address, “Fragile” labels, and arrows indicating “This side up.” Place a signed custody seal over the cooler lid.

Laboratory Sample Custody Procedures (receipt of samples, archiving, and disposal):

Laboratory COC begins when samples are received and continues until samples are discarded. Sample custodians will receive the incoming samples, sign the accompanying COC forms, and retain copies of the COC forms as permanent records. The laboratory sample custodians will record the pertinent information concerning the samples, including the persons delivering the samples, the date and time received, sample condition at the time of receipt (sealed, unsealed, or broken container; temperature at laboratory receipt; or other relevant remarks), the sample identification numbers, and the unique laboratory identification numbers for the samples. This information should be entered into a computerized laboratory information management system (LIMS). The laboratory is responsible for maintaining records necessary to maintain custody throughout sample preparation and analysis.

The laboratory will provide a secure storage area for the samples. Access to this area will be restricted to authorized personnel. The custodian will confirm that samples requiring special handling, including samples that are heat- or light-sensitive, radioactive, or have other unusual physical characteristics, will be properly stored and maintained prior to analysis. Laboratory SOPs for sample custody, tracking, archiving and disposal are located at the laboratory and are available upon request.

QAPP WORKSHEET #27: SAMPLE CUSTODY REQUIREMENTS (CONTINUED)

Sample Identification Procedures:

A sample numbering system will be used to identify each sample collected for laboratory analysis. The numbering system will ensure that each sample is uniquely identified and will allow for retrieval of sample information about a particular sample location from a database. Parent samples and quality control samples will use the following formats for sample IDs:

Parent Sample	Well ID_YYYYMMDD	Ex: SC36D_20190731
Duplicate	DUP-XX	Ex: DUP-01
Matrix Spike	Well ID_ YYYYMMDD_MS	Ex: SC36D_20190731_MS
Matrix Spike Duplicate	Well ID_ YYYYMMDD_MSD	Ex: SC36D_20190731_MSD
Equipment Blank	EB_ YYYYMMDD	Ex: EB_20190731
Field Blank	FB_ YYYYMMDD	Ex: FB_20190731
Trip Blank	TB_ YYYYMMDD	Ex: TB_20190731

The sample identification given to duplicate samples will be consecutively numbered blind duplicate IDs, the project name, project number, preservative and date collected will be the only identifying information on the label, the time, well identification and sampler's initials sections of the label will all be left blank.

Duplicate sample example: duplicate for a groundwater sample collected from SC20S as the second duplicate of the sampling event on 25 September 2017 would be as follows: DUP-02.

Sample Labels

A sample label will be affixed to the sample containers, appropriate for the site and sample location. The label will be completed with the following information:

- Project name;
- Sample identification number;
- Date and time of sample collection;
- Preservative used (if applicable);
- Sample collector's initials.

Sample Documentation

Documentation during sampling is essential to confirm proper sample identification. Field personnel will adhere to the following general guidelines for maintaining field documentation:

- Documentation will be completed in permanent ink.
- All entries will be legible.
- Errors will be corrected by crossing out with a single line and then dating and initialing the lineout.
- Any serialized documents will be maintained in the project file and referenced in the site logbook.
- Unused portions of pages will be crossed out, and each page will be signed and dated.

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Alkalinity
Analytical Method/SOP: SM 2320B-1997 or EPA 310.1; WI11475

QC Sample	Number/Frequency	Method/SOP Acceptance Criteria	Corrective Action	Title/position of person responsible for corrective action	Project-Specific MPC
Method blank	1 per prep batch of up to 20 samples	No analytes detected > LOQ or >1/10 the amount measured in any sample	Reanalyze blank to confirm detections. If detects confirm, reanalyze samples that are not ND or not >10x the blank value.	ELLE Analyst	See Worksheet #12
LCS	1 per prep batch of up to 20 samples	Laboratory statistical window	Reanalyze LCS and associated samples. Analytes in the LCS that fail high and are ND in the samples can be reported. All others are re-analyzed.	ELLE Analyst	See Worksheet #12
Laboratory Duplicate	1 per 10 samples	Laboratory statistical RPD	Flag data	ELLE Analyst	See Worksheet #12
Field Duplicate	1 per 20 samples	RPD <30%	Flag Data	Geosyntec Project QAM	See Worksheet #12
Equipment Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12
Field Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12

Acronym list

LCS – Laboratory Control Sample

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Alkalinity (continued)
Analytical Method/SOP: SM 2320B-1997 or EPA 310.1; WI11475

Acronym list (continued)

LOQ – Limit of Quantification
MPC - Measurement Performance Criteria
ND – None Detected
RPD – Relative Percent Difference
SOP – Standard Operating Procedures

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Sulfide
Analytical Method/SOP: SM 4500 S2D/EPA 376.2; WI11483

QC Sample	Number/Frequency	Method/SOP Acceptance Criteria	Corrective Action	Title/position of person responsible for corrective action	Project-Specific MPC
Method blank	1 per prep batch of up to 20 samples	No analytes detected > 1/2 LOQ or >1/10 the amount measured in any sample	Reanalyze blank to confirm detections. If detects confirm, reanalyze samples that are not ND or not >10x the blank value.	ELLE Analyst	See Worksheet #12
Matrix Spike	1 per 20 samples	Laboratory statistical or method window and RPD, whichever is tighter	Flag outliers	ELLE Analyst/ Geosyntec Project QAM	See Worksheet #12
LCS	1 per prep batch of up to 20 samples	Laboratory statistical or method window and RPD, whichever is tighter	Reanalyze LCS and associated samples. Analytes in the LCS that fail high and are ND in the samples can be reported. All others are re-analyzed.	ELLE Analyst	See Worksheet #12
Laboratory Duplicate	1 per 10 samples	Laboratory statistical RPD	Flag data	ELLE Analyst	See Worksheet #12
Field Duplicate	1 per 20 samples	RPD <30%	Flag Data	Geosyntec Project QAM	See Worksheet #12
Equipment Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Sulfide (continued)
Analytical Method/SOP: SM 4500 S2D/EPA 376.2; WI11483

QC Sample	Number/Frequency	Method/SOP Acceptance Criteria	Corrective Action	Title/position of person responsible for corrective action	Project-Specific MPC
Field Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12

Acronym list

LCS – Laboratory Control Sample
LOQ – Limit of Quantification
MPC - Measurement Performance Criteria
ND – None Detected
RPD – Relative Percent Difference
SOP – Standard Operating Procedures

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Wet Chemistry – Inorganic Ions by IC (NO3 and SO4)
Analytical Method/SOP: EPA 300.0/9056; WI11626

QC Sample	Number/Frequency	Method/SOP Acceptance Criteria	Corrective Action	Title/position of person responsible for corrective action	Project-Specific MPC
Method blanks	1 per prep batch of up to 20 samples	No analytes detected <MDL or >1/10 the amount measure in any sample.	Reanalyze to confirm detections. If detects confirm re-extract samples that are not ND or not >10x the blank value	ELLE Analyst	See Worksheet #12
Matrix Spike	1 per 20 samples	Method limits	Flag outliers	ELLE Analyst/ Geosyntec Project QAM	See Worksheet #12
LCS	1 per prep batch of up to 20 samples	Method limits	Reanalyze LCS and associated samples. Analytes in the LCS that fail high and are ND in the samples can be reported. All others are re-extracted.	ELLE Analyst	See Worksheet #12
Laboratory Duplicate	1 per 10 samples	Laboratory statistical	Flag outliers	ELLE Analyst	See Worksheet #12
Field Duplicate	1 per 20 samples	RPD <30%	Flag Data	Geosyntec Project QAM	See Worksheet #12
Equipment Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12
Field Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Wet Chemistry – Inorganic Ions by IC (NO3 and SO4) (continued)
Analytical Method/SOP: EPA 300.0/9056; WI11626

Acronym list

LCS – Laboratory Control Sample
LOQ – Limit of Quantification
MPC - Measurement Performance Criteria
ND – None Detected
RPD – Relative Percent Difference
SOP – Standard Operating Procedures

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Orthophosphate as Phosphorous
Analytical Method/SOP: EPA 365.3; WI11511

QC Sample	Number/Frequency	Method/SOP Acceptance Criteria	Corrective Action	Title/position of person responsible for corrective action	Project-Specific MPC
Method blank	1 per prep batch of up to 20 samples	No analytes detected > LOQ or >1/10 the amount measured in any sample	Reanalyze blank to confirm detections. If detects confirm, reanalyze samples that are not ND or not >10x the blank value.	ELLE Analyst	See Worksheet #12
Matrix Spike	1 per 20 samples	Laboratory statistical windows	Flag outliers	ELLE Analyst/ Geosyntec Project QAM	See Worksheet #12
LCS	1 per prep batch of up to 20 samples	Laboratory statistical windows	Reanalyze LCS and associated samples. Analytes in the LCS that fail high and are ND in the samples can be reported. All others are re-analyzed.	ELLE Analyst	See Worksheet #12
Laboratory Duplicate	1 per 20 samples	Laboratory statistical RPD	Flag data	ELLE Analyst	See Worksheet #12
Field Duplicate	1 per 20 samples	RPD <30%	Flag Data	Geosyntec Project QAM	See Worksheet #12
Equipment Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Orthophosphate as Phosphorous (continued)
Analytical Method/SOP: EPA 365.3; WI11511

QC Sample	Number/Frequency	Method/SOP Acceptance Criteria	Corrective Action	Title/position of person responsible for corrective action	Project-Specific MPC
Field Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12

Acronym list

LCS – Laboratory Control Sample
LOQ – Limit of Quantification
MPC - Measurement Performance Criteria
ND – None Detected
RPD – Relative Percent Difference
SOP – Standard Operating Procedures

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Total Organic Carbon
Analytical Method/SOP: SM 5310C/EPA 415.1; WI11637

QC Sample	Number/Frequency	Method/SOP Acceptance Criteria	Corrective Action	Title/position of person responsible for corrective action	Project-Specific MPC
Method blanks	1 per prep batch of up to 20 samples	No analytes detected 1/2 LOQ or >1/10 the amount measured in any sample or 1/10 the regulatory limit, whichever is greater	Reanalyze blank to confirm detections. If detects confirm, re-prep samples that are not ND or not >10x the blank value.	ELLE Analyst	See Worksheet #12
Matrix Spike	1 per 20 samples	Laboratory statistical limits for compounds and RPD	Flag outliers	ELLE Analyst/ Geosyntec Project QAM	See Worksheet #12
LCS	1 per prep batch of up to 20 samples	Laboratory statistical limits for compounds and RPD	Correct problem, re-prepare and reanalyze the LCS and all sample associated	ELLE Analyst	See Worksheet #12
Laboratory Duplicate	1 per 10 samples	Laboratory statistical RPD	Flag data	ELLE Analyst	See Worksheet #12
Field Duplicate	1 per 20 samples	RPD <30%	Flag Data	Geosyntec Project QAM	See Worksheet #12
Equipment Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12
Field Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Total Organic Carbon (continued)
Analytical Method/SOP: SM 5310C/EPA 415.1; WI11637

Acronym list

LCS – Laboratory Control Sample
LOQ – Limit of Quantitation
MPC - Measurement Performance Criteria
ND – None Detected
RPD – Relative Percent Difference
SOP – Standard Operating Procedures

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Total Dissolved Solids (TDS)
Analytical Method/SOP: SM 2540 C-2011; WI11597

QC Sample	Number/Frequency	Method/SOP Acceptance Criteria	Corrective Action	Title/position of person responsible for corrective action	Project-Specific MPC
Method blank	1 per prep batch of up to 20 samples	No analytes detected > LOQ or >1/10 the amount measured in any sample	Reanalyze blank to confirm detections. If detects confirm, re-prep samples that are not ND or not >10x the blank value.	ELLE Analyst	See Worksheet #12
LCS	1 per prep batch of up to 20 samples	Laboratory statistical windows	Correct problem, re-prepare and reanalyze the LCS and all sample associated	ELLE Analyst	See Worksheet #12
Laboratory Duplicate	1 per 10 samples	Method Relative Percent Difference	Flag data	ELLE Analyst	See Worksheet #12
Field Duplicate	1 per 20 samples	Relative Percent Difference <30%	Flag Data	Geosyntec Project QAM	See Worksheet #12
Equipment Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12
Field Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12

Acronym list

LCS – Laboratory Control Sample
LOQ – Limit of Quantitation
MPC - Measurement Performance Criteria
ND – None Detected
SOP – Standard Operating Procedures

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Dissolved Hydrocarbons (Methane, Ethane, Ethene)
Analytical Method/SOP: RSK175 or SW-846 8015C or D/WI9796

QC Sample	Number/Frequency	Method/SOP Acceptance Criteria	Corrective Action	Title/position of person responsible for corrective action	Project-Specific MPC
Surrogate Spike	Per Sample (including Blanks, LCS/D, MS/D	Laboratory statistical limits	Reanalyze if outside limits, if confirmed, report	ELLE Analyst	See Worksheet #12
Method Blanks	1 per prep batch of up to 15 samples	No analytes detected > RL or >1/10 the amount measured in any sample	Reanalyze to confirm detections	ELLE Analyst	See Worksheet #12
Matrix Spike	1 per prep batch of up to 20 samples	Laboratory statistical limits, RPD ≤30%	Flag outliers	ELLE Analyst/ Geosyntec Project QAM	See Worksheet #12
LCS/D	1 per prep batch of up to 15 samples	Laboratory statistical limits, RPD ≤20%	Reanalyze LCS and associated samples. Analytes in the LCS that fail high and are ND in the samples can be reported.	ELLE Analyst	See Worksheet #12
Field Duplicate	1 per 20 samples	RPD <30%	Flag Data	Geosyntec Project QAM	See Worksheet #12
Equipment Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12
Field Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Dissolved Hydrocarbons (Methane, Ethane, Ethene) (continued)
Analytical Method/SOP: RSK175 or SW-846 8015C or D/WI9796

QC Sample	Number/Frequency	Method/SOP Acceptance Criteria	Corrective Action	Title/position of person responsible for corrective action	Project-Specific MPC
Trip Blank	1 per cooler	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12

Acronym list

LCS/D – Laboratory Control Sample/ Duplicate
MPC - Measurement Performance Criteria
ND – None Detected
RL – Reporting Limit
RPD – Relative Percent Difference
SOP – Standard Operating Procedures

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Metals (Total and Dissolved Iron)
Analytical Method/SOP: EPA 200.8 WI11933

QC Sample	Number/Frequency	Method/SOP Acceptance Criteria	Corrective Action	Title/position of person responsible for corrective action	Project-Specific MPC
Method Blank	1 per prep batch of up to 20 samples	No analytes detected > 1/2 LOQ or 2.2x MDL, whichever is greater, or >1/10 the amount measured in any sample.	Reanalyze blank to confirm detections. If detects confirm, re-digest samples that are not ND or not >10x the blank value.	ELLE Analyst	See Worksheet #12
Matrix Spike	1 per prep batch of up to 20 samples	Recovery limits 70 - 130%; RPD ≤20%	Analyze post digestion spike and serial dilution	ELLE Analyst/ Geosyntec Project QAM	See Worksheet #12
LCS/LCSD	1 per prep batch of up to 20 samples	Recovery limits 85 - 115%; RPD ≤20%	Analytes in the LCS that fail high and are ND in the samples can be reported. All others are re-digested and reanalyzed.	ELLE Analyst	See Worksheet #12
Laboratory Duplicate	1 per prep batch of up to 20 samples	RPD must be ≤20%	Flag data	ELLE Analyst	See Worksheet #12
Serial Dilutions	Must be prepared with each background sample, evaluated only when analyte concentrations are >50x the MDL	The percent difference must be ≤10%	Flag data	ELLE Analyst	See Worksheet #12

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Metals (Total and Dissolved Iron) (continued)
Analytical Method/SOP: EPA 200.8 WI11933

QC Sample	Number/Frequency	Method/SOP Acceptance Criteria	Corrective Action	Title/position of person responsible for corrective action	Project-Specific MPC
Post Digestion Spike (PDS)	Prepare with each background sample	± 15% True Value	No specific action needed unless required by the project. PDS is reported in data package	ELLE Analyst	See Worksheet #12
Field Duplicate	1 per 20 samples	RPD <30%	Flag Data	Geosyntec Project QAM	See Worksheet #12
Equipment Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12
Field Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12

Acronym list

LCS/LCSD – Laboratory Control Sample / Laboratory Control Sample Duplicate
LOQ – Limit of Quantitation
MPC - Measurement Performance Criteria
MDL - Method Detection Limit
ND – None Detected
PDS - Post Digestion Spike
RPD – Relative Percent Difference
SOP – Standard Operating Procedures

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Eurofins Lancaster Laboratories Environmental, Lancaster, PA
Matrix: Groundwater
Analytical Group: Perchlorates
Analytical Method/SOP: SW-846 6850/WI9989

QC Sample	Number/Frequency	Method/SOP Acceptance Criteria	Corrective Action	Title/position of person responsible for corrective action	Project-Specific MPC
Method blanks	1 per prep batch of up to 20 samples	No analytes detected > RL or >1/10 the amount measured in any sample	Reanalyze to confirm detections. If detects confirm reextract samples that are not ND or not >10x the blank value	ELLE Analyst	See Worksheet #12
Matrix Spike	1 per prep batch of up to 20 samples	Laboratory statistical limits	Flag outliers	ELLE Analyst/ Geosyntec Project QAM	See Worksheet #12
LCS/LCSD	1 per prep batch of up to 20 samples	Laboratory statistical limits	Analytes in the LCS that fail high and are ND in the samples can be reported. All others are re-extracted.	ELLE Analyst	See Worksheet #12
Field Duplicate	1 per 20 samples	RPD <30%	Flag Data	Geosyntec Project QAM	See Worksheet #12
Equipment Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12
Field Blank	1 per day or 1 per 20 samples whichever is greater	No detected target compounds	Flag Data	Geosyntec Project QAM	See Worksheet #12

Acronym list

LCS/LCSD – Laboratory Control Sample / Laboratory Control Sample Duplicate
MPC - Measurement Performance Criteria
ND – None Detected
RL – Reporting Limit
SOP – Standard Operating Procedures

QAPP WORKSHEET #28: ANALYTICAL QUALITY CONTROL AND CORRECTIVE ACTION (CONTINUED)

Laboratory: Environmental Isotope Geochemistry Laboratory: University of Delaware, Newark, DE
Matrix: Groundwater
Analytical Group by Method/SOP: CSIA Perchlorate analysis[1]

QC Sample	Number/Frequency	Method/SOP Acceptance Criteria	Corrective Action	Title/position of person responsible for corrective action	Project-Specific MPC
Laboratory Duplicate	1 per prep batch of up to 10 samples	Within analytical uncertainty (typically ±0.5‰)	Flag outliers	University of Delaware Analyst	See Worksheet #12
Field Duplicate	1 per 10 samples	RPD <30%	Flag Data	Geosyntec Project Quality Assurance Manager	See Worksheet #12

1. There is no SOP for CSIA sampling, protocols will be based on the Environmental Isotope Geochemistry Laboratory Instructions for Perchlorate Collection Field Columns (Appendix C of the Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation) with any updates required.

QAPP WORKSHEET #29: PROJECT DOCUMENTS AND RECORDS

Document	Where Maintained
Field Records: Field logbooks, COC records/forms, QAPP deviations, communications and reports, photographs, GPS printouts	Maintained at Geosyntec until after completion of the project. Files will be archived at Geosyntec project office and included in reports submitted to USEPA.
Laboratory Analytical Records: Raw and summary data, COC and sample receipt forms, sample and instrument logs	Maintained at Geosyntec until after completion of the project. Files will be archived at Geosyntec project office and included in reports submitted to USEPA.
Data Assessment and QA Records: Data validation report, independent technical review forms, CA communications and reports	Maintained at Geosyntec until after completion of the project. Files will be archived at Geosyntec project office and included in reports submitted to USEPA.
Reports: Drafts, final reports, communications of progress and deviations	Maintained at Geosyntec until after completion of the project. Files will be archived at Geosyntec project office and included in reports submitted to USEPA.

Documents and Records

Documentation is critical for evaluating the success of any environmental data collection activity. The following sections discuss the requirements for documenting field activities and for preparing laboratory data packages. This worksheet also lists documents and reports that will be generated as a result of this project.

Field Documentation

Complete and accurate documentation is essential to demonstrate that field measurement and sampling procedures are carried out as described in this QAPP. Field personnel will use permanently bound field logbooks with sequentially numbered pages to record and document field activities. The field logbook will list the contract name and number, the site name, and the names of subcontractors, the service client, and the Project Manager. At a minimum, the following information will be recorded in the field logbook:

- Name and affiliation of all onsite personnel or visitors;
- Weather conditions during the field activity;
- Summary of daily activities and significant events;
- Notes of conversations with coordinating officials;
- References to other field logbooks or forms that contain specific information;
- Discussions of problems encountered and the resolution;
- Discussions of deviations from the QAPP or other governing documents; and
- Description of all photographs taken.

If significant changes to the sampling program are needed because of unanticipated site conditions, this QAPP will need to be amended and submitted to the USEPA Region 2 for review and approval. The field logbook will provide documentation of the deviation from this QAPP and a brief rationale.

QAPP WORKSHEET #29: PROJECT DOCUMENTS AND RECORDS (CONTINUED)

Laboratory Documentation and Data Packages

The analytical laboratory performing analysis will provide full data packages, which contain the information required for data validation. The data packages must contain any of the following elements that are applicable to the analysis to enable data validation:

- Title page;
- Table of contents;
- Data package narrative;
- Final data report tables;
- Analytical records:
  - – Instrument tuning (GC/MS methods);
  - – RTs and RT windows for GC/ECD analyses;
  - – Calibration data;
  - – Calibration verifications;
  - – Surrogate recoveries (GC/MS and GC methods);
  - – Internal standard RT checks and area counts for GC/MS analyses and internal standard recoveries for ICP/MS analyses;
  - – The QC data required by the analytical method and/or the QAPP (blanks, LCS/LCSD, MS/MSD, and laboratory and field duplicates);
  - – Chromatograms for GC/ECD and GC/MS samples, calibrations, and QC samples;
  - – Mass spectra for GC/MS analyses;
  - – Required supporting information;
  - – The sample custody documentation, including sample receipt forms;
  - – Sample processing and spiking records;
  - – Copies of standard preparation logs for each standard used in sample preparation and instrument calibration;
  - – Run logs;
  - – Raw data associated with field and QC data;
  - – Chromatograms
- Documentation of manual integrations;
- List of current MDLs and RLs for the preparation and analysis methods used for sample processing.

QAPP WORKSHEET #29: PROJECT DOCUMENTS AND RECORDS (CONTINUED)

Data Package Format

The analytical laboratory will provide electronic data deliverables (EDDs) for each analytical report. An automated laboratory information management system (LIMS) must be used to produce the EDDs. Manual creation of the deliverable (data entry by hand) is unacceptable. The laboratory will verify EDDs internally before they are issued. The EDDs will correspond exactly to the hard-copy data. No duplicate data will be submitted. EDDs will be delivered in the appropriate format per USEPA Region 2 requirements as applicable. Data will be archived by the laboratory and by the Project Coordinator's office for a minimum of 10 years.

QAPP WORKSHEET #30: ANALYTICAL SERVICES

Matrix	Analytical Group	Concentration Level	Sample Locations/ID Number	Analytical SOP or Method	Data Package Turnaround Time	Laboratory / Organization (name and address, contact person and telephone number)	Backup Laboratory / Organization (name and address, contact person and telephone number)
Groundwater	Perchlorate	Low	See Worksheet #18	WI9989	28 Days	Eurofins Lancaster Laboratories Environmental, LLC 2425 New Holland Pike Lancaster, PA 17601 (717) 556-7290 Certification #PA011; certification is current	SGS North America 2235 US Highway 130 Dayton, NJ 08810 (732) 329-0200
Groundwater	Nitrate	Low		WI11626	Standard (10-15 business days)		
Groundwater	Sulfate	Low		WI11626			
Groundwater	Orthophosphate as Phosphorous	Low		WI11511			
Groundwater	Alkalinity	Low		WI11475			
Groundwater	TOC	Low		WI11637			
Groundwater	TDS	Low		WI11597			
Groundwater	Sulfide	Low		WI11483			
Groundwater	Iron (Total and Dissolved)	Low		WI11933			
Groundwater	Methane	Low		WI9015178			
Groundwater	Ethane	Low		WI9015178			
Groundwater	Ethene	Low		WI9015178			

Acronym list

DOC - Dissolved Organic Carbon
NA - Not Applicable
SOP – Standard Operating Procedures
TDS – Total Dissolved Solids
TOC – Total Organic Carbon

QAPP WORKSHEET #30: ANALYICAL SERVICES (CONTINUED)

Matrix	Analytical Group	Concentration Level	Sample Locations/ID Number	Analytical SOP or Method	Data Package Turnaround Time	Laboratory / Organization (name and address, contact person and telephone number)	Backup Laboratory / Organization (name and address, contact person and telephone number)
Groundwater	CSIA	Low	See Worksheet #18	ESTCP: Guidance Manual for Forensic Analysis of Perchlorate in Groundwater using Chlorine and Oxygen Isotopic Analyses[1]	Standard (90-120 days)	Environmental Isotope Geochemistry Laboratory: University of Delaware, 221 Academy St, ISE lab 458, Newark DE 19716 (302) 831-8022	NA
Groundwater	Gene-Trac®	NA	See Worksheet #18	Gene-Trac®	Standard (10 business days)	SiREM	NA

1. This guidance document is provided in the Revised Field Sampling Plan for OU3 Supplemental Remedial Investigation, Appendix C. There is no SOP for CSIA sampling, protocols will be based on the provided guidance document with any updates required

Acronym list

DOC - Dissolved Organic Carbon
NA - Not Applicable
SOP – Standard Operating Procedures
TDS – Total Dissolved Solids
TOC – Total Organic Carbon

QAPP WORKSHEET #31: PLANNED PROJECT ASSESSMENTS

Assessment Type	Frequency	Internal or External	Organization Performing Assessment	Person(s) Responsible for Performing Assessment (title and organizational affiliation)	Person(s) Responsible for Responding to Assessment Findings (title and organizational affiliation)	Person(s) Responsible for Identifying and Implementing Corrective Actions (CA) (title and organizational affiliation)	Person(s) Responsible for Monitoring Effectiveness of CA (title and organizational affiliation)
Offsite Laboratory Technical Systems Audit	Per Laboratory QA Manual	Internal	Eurofins Lancaster Laboratories Environmental	Per Laboratory QA Manual	Per Laboratory QA Manual	Laboratory Personnel	Per Laboratory QA Manual
Data Quality Assessment (data validation reports)	Upon receipt of analytical data packages	Internal	Geosyntec	Analytical Data QA Manager	Laboratory PM, Eurofins Lancaster Laboratories Environmental	Laboratory	Analytical Data QA Manager

Acronym list
QA – Quality Assurance

QAPP WORKSHEET #32: ASSESSMENT FINDINGS AND CORRECTIVE ACTION RESPONSES

Assessment Type	Nature of Deficiencies Documentation	Individual(s) Notified of Findings (name, title, organization)	Timeframe of Notification	Nature of Corrective Action Response Documentation	Individual(s) Receiving Corrective Action Response (name, title, organization)	Timeframe for Response
Offsite Laboratory Technical Systems Audit	Internal Audit Report	Laboratory Manager/ Laboratory Technical Director/ Laboratory Operations Manager	Annual audit	Per Individual Laboratory QA Manual	Analytical Data QA Manager	Per Individual laboratory QA Manual
Data Quality Assessment	Data Validation Report	Project QA Manager- Livia Capaldi	Upon receipt of analytical data package	Corrective Action from Laboratory	Project Manager- Seth Kellogg Project QA Manager- Livia Capaldi	Within two weeks of issuance of DQAR

Acronym list

DQAR – Data Quality Assessment Report

QA – Quality Assurance

QAPP WORKSHEET #32: ASSESSMENT FINDINGS AND CORRECTIVE ACTION RESPONSES (CONTINUED)

ASSESSMENT

This worksheet addresses assessment of the effectiveness of the project implementation and the associated QA/QC activities.

Field Assessment and Response Actions

To monitor the capability and performance of the field activities, field inspections will be performed as follows.

The Field Manager will supervise work activities and ensure that they are performed in accordance with plans and specifications. Any problems or concerns will be immediately discussed with the Geosyntec project manager, the client respondent and USEPA Region 2 RPM as appropriate. An appropriate corrective action (CA) developed, reviewed and implemented. The CA will be documented.

Equipment Inspections

Documented inspections will be performed daily on all equipment prior to and during their use to ensure the equipment is in safe operating condition. Field Personnel will perform these inspections and will alert the field manager immediately if an issue arises.

Preventative maintenance procedures recommended by the manufacturer will be followed. Any equipment found to be unsafe will be flagged and its use prohibited until unsafe conditions have been corrected. Replacement equipment will be delivered to site as quickly as possible if a piece of equipment is discovered to be faulty.

Verification and Testing Procedures

Non-conformance/CA

Non-conforming items and activities are those that do not meet the project requirements. When such a condition is identified, Geosyntec will implement a CA program to:

- Document the non-conforming item or procedure and determine the cause of the non-conformance and its effect on project performance and the integrity of completed work;
- Correct or replace the non-conforming item in the most efficient and effective manner; and
- Verify and document that the corrective action taken is successful.

Documentation of Non-Conforming Items

The Field Manager will document any non-conforming item in the field logbook. This list will clearly state what is out of compliance, the date the noncompliance was originally discovered, and the date the work was corrected.

QAPP WORKSHEET #32: ASSESSMENT FINDINGS AND CORRECTIVE ACTION RESPONSES (CONTINUED)

Implementation of CA

Geosyntec will stop work on any item or feature pending satisfactory correction of the deficiency noted by the Project Manager or the USEPA Region 2 RPM. The Project Manager and Field Manager will have the authority to stop work until CAs are implemented. In some cases, the CA may be obvious and may be implemented immediately upon identification of the non-conformance. Others may require additional input from technical and/or operations staff, additional equipment and/or materials, or changes in existing structures or completed work. The Project Manager and Field Manager will not allow work to be added to or built upon non-conforming work unless the USEPA Region 2 RPM concurs that the correction can be made without disturbing continuing work.

Verification and Documentation of CA

Non-Conformance/QC Reporting

A non-conformance is defined as an identified or suspected deficiency or discrepancy with regard to an approved document (e.g., improper sampling procedures, improper instrument calibration, calculation error); or an item where the quality of the end product itself or subsequent activities using the document or item would be affected by the deficiency; or an activity that is not conducted in accordance with the established plans or procedures.

Any team member engaged in project work that discovers or suspects a non-conformance is responsible for informing the Project Manager or Field Manager. The Project Manager will evaluate each non-conformance and provide a disposition, which describes the actions to be taken and notify the USEPA Region 2 RPM per the communication pathway time frame specified by this QAPP.

The Project Manager or Field Manager will verify that no further project work that is dependent on the non-conforming item or activity is performed until the situation has been corrected back to the original condition intended by the project documentation. Documentation of the non-conformance and CA, along with the appropriate verification and approval signatures, will be included in the project file. Copies of the non-conformances will be maintained by the Project Manager.

The Field Manager will verify successful completion of CAs for non-conformances on a follow-up inspection. The Weekly Activity Report will reflect all CAs completed. The Field Manager will also update the re-work item list with the CA taken and the date the CA was completed. Recurring non-conformances of similar nature will be investigated to determine the root cause of the problem so as to eliminate or minimize future occurrences of the non-conformance.

INTERNAL LABORATORY AUDITS

As part of its QA program, the laboratory QA manager will conduct audits of the analytical systems to verify that the systems are working properly, and personnel are adhering to established procedures and documentation practices. These audits will also assist in determining or detecting where problems are occurring. In addition to conducting internal audits, as part of its established QA program, the laboratory is required to take part in regularly scheduled semi-annual performance evaluation (PE) studies and laboratory audits from state and federal agencies, as defined by the agencies. Each laboratory selected to support this project must maintain current NELAP accreditation.

QAPP WORKSHEET #32: ASSESSMENT FINDINGS AND CORRECTIVE ACTION RESPONSES (CONTINUED)

Laboratory CAs

If a particular laboratory analysis is deemed "out of control," CA will be taken by the laboratory to maintain continued data quality. Each laboratory must adhere to their in-house CA policy.

QAPP WORKSHEET #33: QA MANAGEMENT REPORTS TABLE

Type of Report	**Frequency** (Daily, weekly monthly, quarterly, annually, etc.)	**Projected Delivery Date(s)**	**Person(s) Responsible for Report Preparation** (title and organizational affiliation)	**Report Recipient(s)** (Project Role)
Daily Activity Reports	Daily throughout duration of field activities	Daily	Field Manager	Project Manager Project File
Weekly or Task Activity Reports	Weekly or following the completion of a field event	Within two days of the completion of a task or if a task is expected to take more than one week then a summary at the end of each week of work	Field Manager	Project Manager Project file
Data Validation Reports to be included in Final Project Report	On-going upon receipt of data deliverables	Per project schedule	Analytical Data QA Manager	Project Manager EPA Region 2 Remedial Project Manager Project file
Corrective Action Reports	Generated on the resolution of identified discrepancies in the field	Immediately upon completion	Team member identifying non-conforming activity or item Project Manager	EPA Region 2 Remedial Project Manager Project file
Final Project Report	At the completion of the assigned project tasks	Per project schedule	Project Manager	EPA Region 2 Remedial Project Manager Project file

QAPP WORKSHEET #33: QA MANAGEMENT REPORTS TABLE (CONTINUED)

Periodic QA Management reports ensure that managers and stakeholders are updated on project status and the results of all QA assessments. Efficient communication of project status and problems allows Project Coordinators to implement timely and efficient corrective actions so that the data meets the DQO requirements for the project. USEPA Region 2 will receive several types of management reports. These will include the results of any CA items and data validation reports. In addition, each report will contain a section on QA. Problems or issues that arise between regular reporting periods may be identified to program management at any time. Information included in a progress report will include but not be limited to the following:

- Results of technical systems audits conducted during the period, as applicable.
- An assessment of any problems.
- A listing of the non-conformance reports including Stop-Work Orders issued during the period, related CA undertaken, and an assessment of the results of these actions.
- Identification of significant QA problems and recommended solutions, as necessary.

Final Project Report

The issues listed in the Worksheet #33 table will be addressed in the QA management reports (as attachments to the final project report) or the QA section of the final project report. The final project report will also address additional data quality concerns, including the following:

- Narrative and timeline of project activities.
- Summary of DQO development.
- Reconciliation of project data with DQOs.
- Summary of major problems encountered and their resolution.
- Data summary, including tables, charts, and graphs with appropriate sample identification or station location numbers, concentration units, percent solids (if applicable), and data quality flags.
- Conclusions and recommendations

QAPP WORKSHEET #34: DATA VERIFICATION AND VALIDATION INPUTS

Verification Input	Description	Internal/External	Responsible for Verification
Planning Documents	Project Planning documents will be evaluated prior to implementation. Examples of items for review will include designs, specifications, health and safety procedures, and work plans in the list of reviewed items. QAPP review items will include personnel, training, laboratories, methods, SOPs, performance requirements, DQOs, forms, QAPPs, location maps, naming conventions, and project specific analytes.	I/E	Project Manager Analytical Data QA Manager Field Manager EPA Region 2 Remedial Project Manager
Field Activity Documentation	The Field Manager will review all documentation recorded by the field team during all field activities. This will include field log books, field data forms (electronic and paper), calibration records, sampling location plans, decontamination records, and daily reports.	I	Field Manager
Field Data	The data generated in the field to support the project will be checked as completed against the requirements of the Project planning documents, specific data collection requirements and applicable field SOPs. The data will be reviewed by the technical lead(s) prior to being included in the final report	I	Field Manager Leader (designated during activity)
COC Documentation	The COC documents will be peer-reviewed in the field prior to shipping of samples. The COC will also be reviewed upon receipt by the laboratory personnel and again by the data reviewers and data validation team upon receiving the analytical data packages.	I/E	Field Manager Task Leader (designated during activity) Analytical Data QA Manager Laboratory Sample Receiving personnel and Laboratory PM
CA and Non-Conformance documentation	Field CA and non-conformance reports from the laboratory will be checked as CA completed. CA taken by the laboratory will be evaluated by the Analytical Data QA Manager. CA completed by the field team will be evaluated by the Field Manager.	I	Project Manager Analytical Data QA Manager Field Manager Project QA Manager

QAPP WORKSHEET #34: DATA VERIFICATION AND VALIDATION INPUTS (CONTINUED)

Verification Input	Description	Internal/External	Responsible for Verification
Analytical Data Packages	Analytical data results will be checked as completed against the requirements of the QAPP, specific method requirements and laboratory SOPs. Analytical data packages will be reviewed by the laboratory prior to release and by the data validation team upon receipt of the data.	I	Analytical Data QA Manager
EDDs	The EDDs will be developed and provided by the laboratories. EDDs will be text files. Concentration and detection limit data will be delivered as string (as opposed to numeric) field types to ensure that the precision (i.e., number of significant digits) intended by the laboratory is represented in the EDDs. EDDs will be reviewed by the laboratory prior to release of the data and by data management and the data validation team upon receipt.	I	Field Manager Analytical Data QA Manager Laboratory Data Base Manager
Quality Control Summary Report	A summary of the laboratory QC sample results will be verified for completeness by the QA team upon receipt of data packages from the laboratory.	I	Analytical QA Manager Field Manager
Data Handling	The entry of data into the database will be evaluated for completeness and accuracy.	I	Field Manager Analytical Data QA Manager Geosyntec Database Manager

Acronym list

COC – Chain of Custody
CA - Corrective Action
DQO - Data Quality Objective
EDD – Electronic Data Deliverables
SOP – Standard Operating Procedures
QA – Quality Assurance

QAPP WORKSHEET #34: DATA VERIFICATION AND VALIDATION INPUTS (CONTINUED)

Step IIa / IIb	Data Validation Input	Description	Responsible for Data Validation
IIa	Methods	Check that the methods used were those specified by the QAPP.	Data Validation Chemist/ Geosyntec Validation Team, Field Manager
IIa/IIb	Performance Requirements	Check that the performance requirements specified by the QAPP are met.	Data Validation Chemist/ Geosyntec Validation Team, Field Manager
IIa	Report Forms	Check that the report forms are filled out completely and as required by the QAPP, method, or guidance documents.	Data Validation Chemist/ Geosyntec Validation Team, Field Manager
IIa	Sampling plans, location maps, grids, and sample ID numbers	Check that the specifications for these items were met as described by the project planning documents and work instructions.	Field Manager, Project Manager, Sampling Team peer review
IIa	SOPs (sampling and analytical)	Check that the requirements as specified by these documents were met and that the methods and SOPs referenced and contained in the QAPP were applied to the data.	Laboratory personnel, Data Validation Chemist/Geosyntec Validation Team, Field Manager
IIa	Project specific analytes	Check that the project specific analytes were reported as listed in the planning documents, specifically the QAPP.	Laboratory personnel, Technical PM, Data Validation Chemist/Geosyntec Validation Team
IIa/IIb	All required elements of the data package	Check that the required reporting elements are present in the laboratory data package.	Laboratory personnel, Data Validation Chemist/Geosyntec Validation Team

QAPP WORKSHEET #34: DATA VERIFICATION AND VALIDATION INPUTS (CONTINUED)

Step IIa / IIb	Data Validation Input	Description	Responsible for Data Validation
IIa/IIb	Sampling/Field documents	Check that the required criteria and specifications for field practices surrounding sample collection, shipping, and handling are met as specified by the project planning documents. The field documentation will be reviewed, including, but not limited to: COCs, communication logs, CA reports, documentation of field and method variances, documentation of internal QA review, EDDs review, field logs, forms, and notebook review, field calibration records, and daily field reports.	Field Manager, Project Manager
IIa/IIb	External Reports	Check that external reports created for and by the project, as applicable, such as external audit reports, laboratory assessments, performance testing results, and NELAP accreditation support the requirements of the QAPP.	Project Manager, Project QA Manager

QAPP WORKSHEET #35: DATA VERIFICATION PROCEDURES

Data Verification

During the data verification process, the laboratory data for each analytical test will be reviewed to evaluate the completeness of the data set with respect to each reference method and/or to the project requirements. This review will include the data received from the laboratory for data associated with the Operable Unit 3 groundwater investigation. Depending on the level of receivables and the stage of data validation required, these records should include the sample preparation procedure, instrument calibration data and continuing calibration data, project sample and QC sample results, sample identifications, and COCs. These records should also include the completion of the records to identify the analyst(s) who performed the testing and the dates and times of sample preparation and analysis. Depending on the level of validation required, the type of calculation may be reviewed for accuracy. It is the job of the data validator to thoroughly review the data package and to record any deviations that may have occurred. It is the responsibility of the assigned laboratory personnel to thoroughly review the data package and to record any deviations that may have occurred in the case narrative. No data will be released to Geosyntec until the internal review and approval processes are complete.

Data Review Process (Steps I, IIa, and IIb)

Prior to release of the data to Geosyntec, the analytical data will be verified by the responsible laboratory. Upon receipt of the analytical data, the data validator will perform the appropriate stage of data validation, checking the compliance, comparison and usability of the data during the data validation process.

Data Review Process Steps		Step I Verification	Step IIa Compliance	Step IIb Comparison	Step III Usability
Planning Documents					
1	Evidence of required approval of plan (QAPP)	X			Uses Outputs from Previous Steps
2	Identification of personnel (those involved in the project and those conducting verification steps)	X			
3	Laboratory Name	X			
4	Methods (sampling and analysis)	X	X		
5	Performance requirements (including QC criteria) for all inputs	X	X	X	
6	Project quality objectives	X	X	X	

QAPP WORKSHEET #35: DATA VERIFICATION PROCEDURES (CONTINUED)

Data Review Process Steps		Step I Verification	Step IIa Compliance	Step IIb Comparison	Step III Usability
Planning Documents (continued)					
7	Reporting forms	X	X		Uses Outputs from Previous Steps
8	Sampling plans, location, maps, grids, and sample ID numbers	X	X		
9	Site identification	X	X		
10	SOPs (sampling and analytical)	X	X		
11	Staff training and certification	X	X		
12	List of project-specific analytes	X	X		
Analytical Data Package					
13	Case narrative	X	X		Uses Outputs from Previous Steps
14	Internal laboratory COC	X	X		
15	Sample condition upon receipt, and storage records	X	X		
16	Sample chronology (time of receipt,	X	X		
	extraction, and analysis				
17	Identification of QC samples (sampling or lab, temporal, and spatial)	X	X		
18	Associated (batch or periodic) PT sample results	X	X	X	
19	Communication Logs	X	X		
20	Copies of laboratory notebook, records, prep sheets	X	X		
21	CA Reports	X	X		
22	Definitions of laboratory qualifiers	X	X	X	
23	Documentation of laboratory method deviations	X	X	X	
24	Documentation of individual QC results (e.g., spike, duplicate, LCS)	X	X	X	

QAPP WORKSHEET #35: DATA VERIFICATION PROCEDURES (CONTINUED)

Data Review Process Steps		Step I Verification	Step IIa Compliance	Step IIb Comparison	Step III Usability
Analytical Data Package (continued)					
25	Documentation of laboratory method deviations	X	X	X	Uses Outputs from Previous Steps
26	EDDs	X	X		
27	Instrument Calibration Reports	X	X	X	
28	Laboratory name	X	X		
29	Laboratory sample identification numbers	X	X		
30	QC sample raw data	X	X	X	
31	QC summary report	X	X	X	
32	Raw data	X	X	X	
33	Reporting forms, completed with actual results	X	X	X	
34	Signatures for laboratory sign-off (e.g., laboratory QA/QC Manager)	X	X		
35	Standards traceability records (to trace standard source from National Institute of Standards and Technology (NIST), for example; completed during Stage 4 data validation)	X	X	X	
Sampling Documents					
36	COC	X	X		Uses Outputs from Previous Steps
37	Communication Logs	X	X		
38	CA results	X	X		
39	Documentation of CA results	X	X	X	
40	Documentation of deviation from methods	X	X	X	
41	Documentation of internal QA review	X	X	X	
42	EDDs	X	X		
43	Identification of QC samples	X	X	X	

QAPP WORKSHEET #35: DATA VERIFICATION PROCEDURES (CONTINUED)

Data Review Process Steps		Step I Verification	Step IIa Compliance	Step IIb Comparison	Step III Usability
Sampling Documents (continued)					
44	Meteorological data from field (e.g., wind, temperature)	X	X	X	Uses Outputs from Previous Steps
45	Sampling instrument decontamination records	X	X		
46	Sampling instrument calibration logs	X	X		
47	Sampling Location and Plan	X	X	X	
48	Sampling notes and drilling logs	X	X	X	
49	Sampling report (from Field Manager to Project Manager describing sampling activities)	X	X	X	
External Reports					
50	External audit report	X	X	X	Uses Outputs from Previous Steps
51	External proficiency testing sample results	X	X		
52	Laboratory certification	X	X		
53	Laboratory QA plan	X	X		
54	MDL study information	X	X	X	
55	NELAP accreditation	X	X		

QAPP WORKSHEET #36: DATA VALIDATION PROCEDURES

Step IIa / IIb	Matrix	Analytical Group	Concentration Level	Validation Criteria	Data Validator (title and organizational affiliation)
IIa/IIb	Groundwater	Analyses listed in WS#15 of this QAPP	Low/Standard	Criteria cited in the QAPP, method and SOP criteria, current National Functional Guidelines for Data Validation, and EPA Region 2 Quality Assurance Guidance and Standard Operating Procedures. Definitive data are required for the EPA approved analytical tests used for measuring groundwater, at the site.	Data Validation Chemist/Geosyntec Validation Team

Data Validation

Stage 2A data validation will be performed manually on 90% of the data associated with the remedial investigation and risk assessment, with the remaining 10% validated at Stage 4. During data validation, the evaluation of the data will extend beyond method, procedural, or contractual compliance (verification) to check the analytical quality of the specific data set. The data will be evaluated with regard to compliance with the DQOs and measurement quality objectives. During data validation, data validation qualifiers will be assigned to provide the basis of describing data quality. Should non-conformance issues be generated from the laboratory, the data validation procedure evaluates the impacts of the nonconformance(s) on the quality and usability of the data set.

Step IIa denotes a list of data validation activities which include the following and are associated with methods, procedures, and contracts (MPC):

- Data Deliverables – Check that the required information on sampling and analysis are provided.
- Analytes – Check that the appropriate analytes were reported, as required.
- COC – Evaluate traceability of data and examine against procedural requirements.
- Holding times – Check analysis holding times.

QAPP WORKSHEET #36: DATA VALIDATION PROCEDURES (CONTINUED)

- Sample Handling – Check that sample preservation, handling, and storage procedures were met.
- Analytical Methods and Procedures – Evaluate whether the required methods and procedures were performed.
- Data Flags – Check that the laboratory flags were defined and used correctly.
- Laboratory Transcription – Check accuracy of transcription, where applicable.
- Standards – Check that standards are traceable and meet project and contract requirements; this is completed as part of Stage 4 data validation.

Step IIb denotes a list of data validation activities which include the following and are associated with comparison with MPC in the QAPP:

- Data Deliverables and QAPP – Check that data report from Step IIa was provided.
- Field Duplicates – Compare results of field duplicates with criteria established in the QAPP.
- Project Quantitation Limits – Check that quantitation limits were achieved as outlined in the QAPP. As part of Stage 4 data validation, check that the laboratory successfully analyzed a standard at the quantitation limit.
- Confirmatory Analysis – Evaluate the agreement of the laboratory results, as appropriate.
- Performance Criteria – Evaluate QC data against project specific performance criteria in the QAPP (i.e., evaluate quality parameters beyond those outlined in the methods).
- Data Qualifiers – Check that the data validation qualifiers applied in Step IIa were those specified in the QAPP and that any deviations were specified.
- Step IIb Data Validation Report – Summarize outcome of comparison of data to MPC in the QAPP, and include qualified data and explanation of the data qualifiers.

QAPP WORKSHEET #37: DATA USABILITY ASSESSMENT

To the extent possible, Geosyntec will follow EPA's data quality assessment (DQA) process to verify that the type, quality, and quantities of data collected are appropriate for their intended use. DQA methods and procedures are outlined in USEPA QA/G9-R Data Quality Assessment, A Reviewer's Guide, February 2006. The DQA process includes five steps: 1) review the DQOs and sampling design; 2) conduct a preliminary data review; 3) select a statistical test; 4) verify the assumptions of the statistical test; 5) draw conclusions from the data.

After the data are received from the fixed based laboratory, data validation of the data will occur as described in Worksheet #36. During data validation, where necessary, data validation qualifiers will be applied to the data indicating that it has limited use, should perhaps be examined more closely, or has dramatically failed one or more data quality indicator criteria and has been rejected. This information will be supplied to the project team via a data validation report and to the data manager through updates to the database. A DQA report will be prepared on a periodic basis summarizing the overall quality of the data including field data, field QC data, laboratory QC data, and laboratory data. This will further illustrate the limitations of any qualified data that may have resulted during data validation.

It is incumbent on the project team to then utilize the data in an appropriate manner based on any limitations that have been identified.

Summarize the usability assessment process and all procedures, including interim steps and any statistics, equations, and computer algorithms that will be used:

Data usability is the process of evaluating the data validation results and determining the confidence with which any data point(s) may be used. Usability is determined by evaluating the data validation qualifier applied and the laboratory QC results. Concentration values may be considered to have a high degree of confidence because the associated method performance criteria were achieved. Estimated concentration results are evaluated with respect to the bias contributed to the value by the associated QC result. Bias direction can be estimated for data quality impacts due to surrogate recoveries, MS recoveries, and LCS recoveries. Sample concentration results that are rejected during data validation are not used in the decision-making process and should not be reported.

Describe the evaluative procedures used to assess overall measurement error associated with the project:

Data usability is evaluated with respect to the DQOs developed in this QAPP to check that the opportunity for incorporating unacceptable and manageable error into the decision-making process is minimized to the extent possible. The DQOs for this project are described in Worksheet #11.

The analytical data, data validation qualifiers, and QC results will be evaluated to determine the confidence with which the analytical data can be used in the project decision-making process. The criteria used in the data usability summary are presented as follows using the data quality indicator criteria required for this project and measured as precision, accuracy, representativeness, completeness, comparability, and sensitivity (PARCCS).

QAPP WORKSHEET #37: DATA USABILITY ASSESSMENT (CONTINUED)

PARCCS Overview

Introduction

This QA program addresses both field and laboratory activities. QA objectives are formally measured through the computation of performance measures known as data quality indicators (DQIs), which are in turn compared to pre-defined measurement quality objectives (MQOs) specific to the project objectives. The DQIs for measurement data are expressed in terms of PARCCS. Evaluation of DQIs provides the mechanism for on-going control and evaluation of data quality throughout the project and ultimately will be used to define the data quality achieved for the various measurement parameters. The field QA program will be accomplished through the collection of QC samples such as field duplicates and trip blanks. The analytical QA program will be assessed through the internal laboratory QC performed, including method blanks, laboratory control sample (LCS) recoveries, surrogate recoveries, and matrix spike/matrix spike duplicate (MS/MSD) recoveries. The following sections describe the DQIs in greater detail, with a discussion of the associated MQOs.

Precision

Precision refers to the reproducibility or degree of agreement among duplicate measurements of a single analyte. The closer the numerical values of the measurements, the more precise the measurement. Poor precision stems from random errors (i.e., mechanisms, which can cause both high and low measurement errors at random). Precision is usually stated in terms of relative percent difference (RPD), but other estimates, such as the relative standard deviation (RSD), range (maximum value minus minimum values), and relative range are common, and may be used pending review of the data.

Precision will be checked through the collection of field duplicates and the analysis of MS/MSD and LCS/LCSD samples for the work performed at the Site. The overall precision of measurement data is a mixture of sampling and analytical factors. Analytical precision is much easier to control and quantify than sampling precision; there are more historical data related to individual method performance, and the “universe” is not limited to the samples received in the laboratory. In contrast, sampling precision is unique to the project. Sampling precision will be measured through the laboratory analysis of field duplicate samples. Laboratory precision will be measured through the analysis of MS/MSD and LCS/LCSD samples.

QAPP WORKSHEET #37: DATA USABILITY ASSESSMENT (CONTINUED)

During the collection of data using field methods and/or instrumentation, precision is checked by reporting several measurements taken at one location and comparing the results. Precision will be determined from duplicate samples and will be expressed as the RPD between replicate/duplicate sample results, computed as follows:

$$RPD = \frac{X_1 - X_2}{(X_1 + X_2)/2} \; x \; 100$$

where *X1* and *X2* are reported concentrations for each replicate sample and subtracted differences represent absolute values. For field duplicates, the precision goal for this project is an RPD of 30%. For laboratory duplicates, the RPD goals are dictated by the specific analytical and laboratory QC acceptance criteria.

Accuracy and Bias

Accuracy refers to the degree of difference between measured or calculated values and the true value. The closer the numerical value of the measurement comes to the true value, or actual concentration, the more accurate the measurement. The converse of accuracy is bias, in which a systematic mechanism tends to consistently introduce errors in one direction or the other. Bias in environmental sampling can occur in one of three ways; these mechanisms and their associated diagnostic and management methods are as follows:

- High bias, which can stem from cross-contamination of sampling, packaging, or analytical equipment and materials. Cross- contamination is monitored through blank samples, such as equipment blanks, trip blanks, and method blanks. These samples assess the potential for cross-contamination from, respectively, sampling equipment, ambient conditions, packaging and shipping procedures, and laboratory equipment. Data validation protocols described in Worksheet #36 present a structured approach for data qualification based on blank samples.
- Low bias, which can stem from the dispersion and degradation of target analytes (e.g., volatilization of chlorinated solvents during field sampling). The effects of these mechanisms are difficult to quantify. Sampling accuracy can be maximized, however, by the adoption and adherence to a strict field QA program. Specifically, sampling procedures will be performed following standard protocols described in the QAPP. Through regular review of field procedures, deficiencies will be documented and corrected in a timely manner.
- High or low bias may occur due to unacceptable recoveries, unacceptable calibration, or other system control problems. The effects of these mechanisms on analytical accuracy may be expressed as the % recovery of an analyte that has been added to the environmental sample at a known concentration before analysis. Analytical accuracy in the laboratory will be determined through the analysis of LCS/LCSDs and MS/MSDs. As with blank samples, data validation protocols provide a structured formula for data qualification based on high or low analyte recoveries.

QAPP WORKSHEET #37: DATA USABILITY ASSESSMENT (CONTINUED)

Accuracy goals are presented as upper and lower control limits for percent recovery and are generated through the compilation of control charts and referenced in each laboratory method SOP.

Representativeness

Representativeness is defined by the degree to which the data accurately and precisely describe a characteristic of a population, parameter variations at a sampling point, a process condition, or an environmental condition. If the results are reproducible, the data obtained can be said to represent the environmental condition. Representativeness is evaluated by collecting sufficient numbers of samples of an environmental medium, properly chosen with respect to place and time. The precision of a representative set of samples reflects the degree of variability of the sampled medium, as well as the effectiveness of the sampling techniques and laboratory analysis.

Completeness

Completeness is defined as the percentage of measurements made which are judged to be valid measurements. The completeness goal is essentially the same for all data uses in that sufficient amounts of valid data are to be generated.

There are limited historical data on the completeness achieved by individual methods. However, the Contract Laboratory Program data have been found to be 80 to 85% complete on a nationwide basis. The percent completeness for each set of samples will be calculated as follows:

$$\%\,Completeness = \frac{Valid\ Data}{Total\ Data\ Planned}\ x\ 100$$

The QA objective for completeness for all parameters will be 90%.

Comparability

Comparability expresses the confidence with which one data set can be compared to another data set measuring the same property. Comparability is evaluated through the use of established and approved analytical methods, consistency in the basis of analysis (e.g., wet weight, volume), consistency in reporting units (µg/L, mg/L), and analysis of standard reference materials. By using standard sampling and analytical procedures, data sets will be comparable.

Sensitivity

Sensitivity refers to the minimum magnitude at which analytical methods can resolve quantitative differences among sample concentrations. If the minimum magnitude for a particular analytical method is sufficiently below an action level or risk screening criterion, then the method sensitivity is deemed sufficient to fully evaluate the dataset with respect to the desired reference values. Frequently, risk-based screening levels fall below the sensitivity of even the most sensitive analytical methods. In such cases, it is necessary to review the qualifications of several laboratories, both from the standpoint of sensitivity as well as other DQIs, to select the best laboratory for the project.

QAPP WORKSHEET #37: DATA USABILITY ASSESSMENT (CONTINUED)

The method detection limit (MDL) is a theoretical limit determined through an MDL study, in which the concentration of a spiked solution is analyzed at least seven times. The standard deviation of the recovered concentrations (σrec) is computed and multiplied by the t-distribution value to arrive at the MDL. Method blank results are also used in the MDL calculations. In practice, to allow for matrix interferences variability in instrument control, a reporting limit of 2.5 to 5 times the MDL is typically selected. The reporting limit (RL) used for each analyte must be supported by an initial calibration that incorporates one or more calibration standards with the concentrations at or below the reported RL.

Analytical sensitivity is readily evaluated by comparing method reporting limits to risk-based screening values. The results of this analysis are presented in Worksheet #15, which demonstrate the suitability of the selected methods to the project requirements.

Identify the personnel responsible for performing the usability assessment:

Data usability is first evaluated by the data validation team, the analytical quality assurance manager, and the laboratory performing the fixed base analysis. Usability of data collected in the field is first determined by the field team and Field Manager. Once the data are validated the usability of the data are determined by the project team, specifically the technical leaders for the project and the Project Manager.

Describe the documentation that will be generated during usability assessment and how usability assessment results will be presented so that they identify trends, relationships (correlations), and anomalies:

Data usability will be documented through validation reports as well as through the issuance of data quality assessment reports (DQARs), which will summarize how the data reflect the specific criteria for the data quality indicators assigned to the project.

APPENDIX B
Standard Operating Procedures

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SOG #NJ1

STANDARD OPERATING GUIDELINE FOR DISSOLVED OXYGEN (DO) CALIBRATION

Geosyntec NJDEP Lab Certification Number: 11022

DATE PREPARED: 12/13/05

DATE REVISED: 04/24/18

SUMMARY:
This is the Standard Operating Guideline (SOG) to be used for the determination of dissolved oxygen in groundwater. This procedure is to be performed by qualified analysts in the field using rented field equipment. The owner of the equipment is responsible for its general care and maintenance. The analyst using this equipment in the field is responsible for calibration and inspection for potential defects in the equipment prior to use. Defective equipment will be returned to the owner and replaced with a new rental. Calibration procedures are to be conducted on the site where the groundwater is to be measured prior to the commencement of groundwater sampling.

EQUIPMENT:
YSI 650MDS with YSI 600 XL/XLM, 6920, or 6820 sonde; YSI 556; or equivalent

METHOD REFERENCE:
Standard Methods for the Examination of Water and Wastewater 4500-O G-11

MAINTENANCE:
Regular maintenance is to be conducted as specified by the manufacturer and owner of equipment. If defects are found in equipment during use, it will be returned to the owner. Equipment will be inspected for defects upon receipt, prior to calibration, and periodically during sampling. The membrane of the DO probe should be inspected prior to each use. If there is any indication that the membrane is worn, torn, has bubbles under it or other material, it will be re-conditioned.

Re-conditioning the DO probe consists of the following procedure*:

1. Install the sonde in the stand with the probes facing up. Do not remove the probe.

2. Put enough solution on the tip of the probe so there is a meniscus.
3. Stretch the membrane over the probe so there are little to no wrinkles in the o-ring seat.
4. Trim the excess membrane to 1/8" from the o-ring. Don't trim right up to the o-ring seat. The membrane will relax over time.
5. Allow the probe to sit in clean water for at least ½ hour to "burn-in". Do not soak in de-ionized water (because this practice is not good for the pH probe).

*The DO membrane on the YSI 556 model is to be replaced by switching the membrane unit with a new unit.

The YSI sonde and probes will be cleaned prior to calibration and use by rinsing with distilled/deionized (DI) water. If contamination or particulate matter is present, a mild detergent will also be used (i.e. alconox).

CALIBRATION STANDARD:
DO calibration is to be conducted by performing a Winkler titration on a weekly basis when DO measurements are made. This procedure shall be performed for each instrument used for the week that it is used in the field. A Winkler Titration is to be performed by US Environmental or equivalent rental company (NJDEP lab certified). DO calibration and Winkler titration will be performed by US Environmental Rental Corporation (US ENV) by following US ENV's SOP titled "Calibration of Dissolved Oxygen sensors for Rental Water Quality Meters" effective 2/21/2012 as attached in this document as Attachment C. All documentation including the date of calibration, name of the analyst performing the calibration, as well as calibration results should be provided by the rental company and retained by the field analyst. Daily DO calibration checks to 100 percent DO saturation and DO check to zero mg/L are to be performed by the field analyst using air saturated water and calibration solutions respectively as described below:

CALIBRATION PROCEDURE (or as specified in site-specific NJDEP approved Work Plan):
Field personnel will check the calibration of field probes consistent with the manufacturer's specifications and the following requirements before sampling:

1. The meter is calibrated daily (at a minimum) prior to field use.
2. For DO calibration, the calibration cup will be rinsed with DI water (a minimal amount or a moist sponge should be left in the bottom of the cell to provide moist air (100% humidity) for calibration; be sure that the tip of the probe is not touching the sponge and is free of water droplets).
3. The calibration cup will be allowed to equilibrate for ten to fifteen minutes.
4. Turn the display unit on by pressing the green power button.
5. Use the arrow buttons to highlight Sonde Menu and press enter.
6. Select Calibrate and press enter.
7. Select DO% and press enter.
8. The screen will read "Enter Barometric Pressure mmHg".
9. The 650 MDS display is equipped with a barometer and the current reading will appear in the box. If the display does not have a barometer, enter a local reading or standard pressure (760 mmHg).
10. Once the desired pressure has been entered, press enter.

11. Observe the DO and temperature readings. When they are stable, press enter. The top of the screen will read, "calibrated".
12. The DO will calibrate to 100% saturation.
13. Record all calibration results on the calibration log.

ZERO DO CALIBRATION CHECK

Field personnel will check the calibration of the field probe by checking the probe with a zero DO solution after calibration. All zero DO checks will be performed prior to use of field equipment each day consistent with the manufacturer's specifications and the following requirements before sampling:

1. After calibration, the meter will be checked to zero DO solution once per day prior to use.
2. Turn the display on by pressing the green power button.
3. Select Sonde run menu.
4. Open the provided zero DO solution (sodium sulfite solution) provided by the rental company.
5. Pour the zero DO solution into calibration cup of the Sonde and attach to the YSI unit.
6. Allow the unit to stabilize for 5 to 15 minutes.
7. Record all calibration check results on the calibration log.

PERCENT DO CALIBRATION CHECK:

Calibration checks will be performed as needed by site-specific sampling procedures and daily after sampling is completed. Initial calibrations and calibration check data will be recorded on the field calibration record provided in Attachment B.

DAILY DUPLICATE

When conducting analysis other than low-flow sampling, a daily duplicate must be taken for pH, specific conductance, and DO measurements at a rate of 1 per 20 measurements. The daily duplicate should be taken within 15 minutes of the field reading and recorded on the DFR or on the form being used for recording the water quality measurements. The acceptance range for DO is within ±.15 mg/L or ±20% calculated relative percent difference.

Relative Percent Difference Calculation:

[(Field value – Duplicate value) / Field value] * 100 = Relative Percent Difference

NOTE:

The calibration of DO must always be conducted following a calibration of specific conductance.

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SOG #NJ2

STANDARD OPERATING GUIDELINE FOR SPECIFIC CONDUCTANCE CALIBRATION

GeoSyntec NJDEP Lab Certification Number: 11022

DATE PREPARED: 12/13/05

DATE REVISED: 04/24/18

SUMMARY:
This is the Standard Operating Guideline (SOG) to be used for the determination of specific conductance in groundwater. This procedure is to be performed by qualified analysts in the field using rented field equipment. The owner of the equipment is responsible for its general care and maintenance. The analyst using this equipment in the field is responsible for calibration and inspection for potential defects in the equipment. Defective equipment will be returned to the owner and replaced with a new rental. Calibration procedures are to be conducted on the site where the groundwater is to be measured prior to the commencement of groundwater sampling.

EQUIPMENT:
YSI 650MDS with YSI 600 XL/XLM, 6920, or 6820 sonde; YSI 556; or equivalent

METHOD REFERENCE:
SM 2510 B-11

MAINTENANCE:
Regular maintenance is to be conducted as specified by the manufacturer and owner of equipment. If defects are found in equipment during use, it will be returned to the owner. Equipment will be inspected for defects upon receipt, prior to calibration, and periodically during sampling. If there is any indication that the equipment is broken or malfunctioning, it will be replaced or returned to the rental company for replacement.

The YSI sonde and probes will be cleaned prior to calibration and use by rinsing with distilled/deionized (DI) water. If contamination or particulate matter is present, a mild detergent will also be used (i.e. alconox).

CALIBRATION STANDARD:
Specific Conductance solution of 1.000 or 1.413 mS/cm will be supplied by the equipment provider. The equipment will also provide a reference for the initial five-point calibration and cell constant check completed by the rental company, and this information shall be copied and maintained in a file.

CALIBRATION PROCEDURE (or as specified in site-specific NJDEP approved Work Plan):
Field personnel shall check the calibration of field probes consistent with the manufacturer's specifications and the following requirements before sampling:

1. The meter is calibrated daily (at a minimum) prior to field use.
2. Turn the display unit on by pressing the green power button.
3. Rinse the calibration cup and probes with a small amount of the calibration standard being used.
4. Fill the calibration cup with conductivity standard and attach to the sonde, making sure to cover the vent hole at the top of the conductivity probe; also ensure there are no air bubbles in the conductivity probe.
5. Use the arrow buttons to highlight Sonde Menu and press enter.
6. Select Calibrate and press enter.
7. Select Conductivity and press enter.
8. Select SpCond and press enter.
9. The screen will read, "Enter SpCond mS/cm".
10. Enter the correct concentration of the conductivity solution that you are using (the specific conductance probe will be calibrated using one point solution (1.000 or 1.413 mS/cm)), and press enter.
11. Observe the specific conductivity reading. (Note: if the conductivity reading is jumping frequently, every 4 seconds, the DO probe may need to be re-conditioned as the conductivity probe will read the DO pulse if there is a hole in the DO membrane or wrinkles in the o-ring seat.)
12. When the conductivity and temperature readings are stable, press enter. The top of the screen will read, "calibrated".
13. Ensure that the calibrated reading is within 1% of the standard (for a solution of 1.000 mS/cm, this corresponds to a range of 0.990 mS/cm to 1.010 mS/cm; for a solution of 1.413mS/cm this corresponds to a range of 1.399 nS/cm to 1.427). If the reading is not accurate to within 1% of the standard, then recalibrate the instrument.
14. Record all calibration results on the calibration log.
15. Remove the probes from the conductivity solution. Rinse the probes with DI water and gently dry them with a paper towel.
16. If calibration was required, a post-calibration check must be performed in the Sonde Run screen. The stabilized check reading should be within 1% of the standard concentration. If the check reading falls outside that range, then re-calibrate the meter following steps 3-13 above.

CALIBRATION CHECK:
An initial calibration will be conducted at the start of each day prior to sampling the groundwater. If the meter requires calibration, the calibration will be checked in the Sonde Run screen. If the check reading is outside the 1% range, the meter must be re-calibrated. Additional calibration checks will be performed as needed by site-specific sampling procedures. Initial calibrations and calibration check data will be recorded on the field calibration record provided in Attachment B.

DAILY DUPLICATE

When conducting analysis other than low-flow sampling, a daily duplicate must be taken for pH, specific conductance, and DO measurements at a rate of 1 per 20 measurements. The daily duplicate should be taken within 15 minutes of the field reading and recorded on the DFR or on the form being used for recording the water quality measurements. The acceptance range for specific conductance is within ±20% calculated relative percent difference.

Relative Percent Difference Calculation:
[(Field value – Duplicate value) / Field value] * 100 = Relative Percent Difference

NOTE:
The calibration of dissolved oxygen must always be conducted following the calibration of specific conductance.

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SOG #NJ3

STANDARD OPERATING GUIDELINE FOR TEMPERATURE CALIBRATION

Geosyntec NJDEP Lab Certification Number: 11022

DATE PREPARED: 12/13/05

DATE REVISED: 04/09/18

SUMMARY:
This is the Standard Operating Guideline (SOG) to be used for the determination of temperature in groundwater. This procedure is to be followed by qualified analysts in the field using rented field equipment. The owner of the equipment is responsible for its general care and maintenance. The analyst using this equipment in the field is responsible for inspection for potential defects in the equipment. Defective equipment will be returned to the owner and replaced with a new rental.

EQUIPMENT:
YSI 650MDS with YSI 600 XL/XLM, 6920, or 6820 sonde; YSI 556; or equivalent

METHOD REFERENCE:
Standard Methods for the Examination of Water and Wastewater 2550 B-0010

MAINTENANCE:
Regular maintenance is to be conducted as specified by the manufacturer and owner of equipment. If defects are found in equipment during use, it will be returned to the owner. Equipment shall be inspected for defects upon receipt, and periodically during sampling. If there is any indication that the equipment is broken or malfunctioning, it will be replaced or returned to the rental company for replacement.

The YSI sonde and probes will be cleaned prior to use by rinsing with distilled/deionized (DI) water. If contamination or particulate matter is present, a mild detergent will also be used (i.e. alconox).

METER CALIBRATION:
The instrument to be used should be calibrated quarterly using a NIST certified thermometer that is graded in 0.2 degree Celsius increments. Meter calibration is to be performed by the rental company (NJDEP lab certified) prior to use in the field. All documentation including the date of calibration, name of the analyst performing the calibration, NIST thermometer identification number, as well as calibration results should be provided by the rental company and retained by the field analyst. These documents are

to be reviewed by the field analyst prior to use of the instrument to ensure the accuracy of the calibration results. Upon review of the calibration results, the field analyst should apply a correction factor to the data when necessary.

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Quality Assurance Officer		Date:

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SOG #NJ4

STANDARD OPERATING GUIDELINE FOR TURBIDITY CALIBRATION

Geosyntec NJDEP Lab Certification Number: 11022

DATE PREPARED: 12/13/05

DATE REVISED: 04/24/18

SUMMARY:
This is the Standard Operating Guideline (SOG) to be used for the determination of turbidity in groundwater. This procedure is to be performed by qualified analysts in the field using rented field equipment. The owner of the equipment is responsible for its general care and maintenance. The analyst using this equipment in the field is responsible for calibration and inspection for potential defects in the equipment. Defective equipment will be returned to the owner and replaced with a new rental. Calibration procedures are to be conducted on the site where the groundwater is to be measured prior to commencement of groundwater sampling.

EQUIPMENT:
YSI 650MDS with 6920, or 6820 sonde; LaMotte 2020; Hach 2100Q or equivalent

METHOD REFERENCE:
SM 2130B-11

MAINTENANCE:
Regular maintenance is to be conducted as specified by the manufacturer and owner of equipment. If defects are found in equipment during use, it will be returned to the owner. Equipment shall be inspected for defects upon receipt, prior to calibration, and periodically during sampling. If there is any indication that the equipment is broken or malfunctioning, it will be replaced or returned to the rental company for replacement.

The YSI sonde and probes will be cleaned prior to calibration and use by rinsing with distilled/deionized (DI) water. If contamination or particulate matter is present, a mild detergent will also be used (i.e. alconox).

The Hach 2100Q or similar meter does not need to be cleaned but must be inspected for any defects. It is imperative that water be kept out of the turbidimeter light chamber (special attention is required to avoid putting wet tubes in the light chamber).

CALIBRATION STANDARDS:
Turbidity standard solutions of 10, 20, 100, and 800 NTU (Hach 2100Q), 1, and 10 NTU (LaMotte) and 0 and 126 NTU (YSI 6820 and 6920) will be provided by the equipment supplier and identification numbers shall be recorded.

CALIBRATION PROCEDURE (YSI or similar or as site Work Plan specifies):
Field personnel will check the calibration of field probes consistent with the manufacturer's specifications and the following requirements before sampling:

1. The meter is calibrated daily (at a minimum) prior to field use and a calibration check is conducted after each calibration and at the end of day..
2. Place ~225 ml 0 NTU calibration standard in the calibration cup and screw the cup onto the sonde, being careful to engage only 1 thread. This ensures that the bottom of the turbidity sensor will not scratch against the bottom of the cup.
3. Turn the display unit on by pressing the green power button.
4. Use the arrow buttons to highlight Sonde Menu and press enter.
5. Select Calibrate and press enter.
6. Select Turbidity and press enter.
7. Select the number of calibration points, 2, and press enter (the turbidity probe will be calibrated using two points (0 and 126 NTU)).
8. Enter the first calibration solution, 0 NTU.
9. Observe the turbidity and temperature readings. When they are stable, press enter. The top of the screen will read, "calibrated".
10. Record all calibration results and calibration lot numbers on the calibration log.
11. Press enter once.
12. Remove the probes from the 0 NTU solution, rinse with DI water, and gently dry with a paper towel.
13. Enter the 2nd calibration solution, 126 NTU. Note: When using AMCO-AEPA standards, the value entered by the user during the calibration protocol is DIFFERENT depending on which YSI turbidity sensor (Legacy 6026 or Current 6136) is being calibrated. This effect is likely due to the larger optical cell volume of the 6136. For example, the label of the YSI 6073 turbidity standard indicates that the value of the standard is 100 NTU when used for calibration of the 6026 sensor, but 126 NTU when used to calibrate the 6136 sensor.
14. Place the probes in the 126 NTU solution.
15. Observe the turbidity and temperature readings. When they are stable, press enter. The top of the screen will read, "calibrated".
16. Ensure that the calibrated reading is within 10% of the standard (when calibrating to 126 NTU, a range of 113-139 is acceptable). If the reading is not accurate to within 10% then recalibrate the instrument.
17. Record all calibration results and calibration lot numbers on the calibration log.
18. Press enter once.
19. Remove the probes from the 126 NTU solution, rinse with DI water, and gently dry with a paper towel.

20. To perform the post calibration check, navigate to the Sonde main screen, highlight Sonde Run and press Enter.
21. Submerge the probes in the 126 NTU solution or 12.7 NTU solution if provided.
22. Observe the turbidity readings. When they are stable, ensure that the turbidity reading is within **10%** of the turbidity standard (for the 126 NTU standard a range of 113.4 – 138.6 is acceptable, for the 12.7 NTU standard a range of 11.4-14.0 is acceptable).
23. Record all calibration check results on the calibration log.

CALIBRATION PROCEDURE (Hach or similar or as site Work Plan specifies):
Field personnel will check the calibration of field instrumentation consistent with the manufacturer's specifications and the following requirements before sampling:

1. The meter is calibrated daily (at a minimum) prior to field use, and a calibration check is conducted after each calibration and at the end of day.
2. Gather the necessary calibration solutions included in the case. Invert each calibration solution 10 times.
3. Wipe the tube of selected calibration solution clean. It is important to use the proper test tubes and to assure the tubes are clean and free from fingerprints, lint, dried spills and significant scratches. A mild detergent may be used to remove dirt or fingerprints. Use lint free tissues to wipe your tubes clean.
4. Turn on the meter and press the "StablCal®" button to enter the calibration menu.
5. Follow the instructions displayed on the screen by inserting the first calibration solution of 20 NTU.
6. Open lid of meter and insert the tube into the chamber by aligning the indexing arrow on the tube with the indexing arrow mark on the meter.
7. Close the lid and push "READ"
8. Repeat steps 5, 6 and 7 for calibration solutions of 100 and 800 NTU.
9. Push "DONE" to complete the 3 point calibration and to review results.
10. Record all calibration results and calibration lot numbers on the calibration log.
11. Upon completion of the "StablCal®" calibration, the meter will automatically enter the Verify Cal mode.
12. Complete the verification by using the calibration solution of 10 NTU.
13. Open lid of meter and insert tube into chamber by aligning the indexing arrow on the tube with the indexing arrow mark on the meter.
14. Close the lid and push "READ"
15. Record the verification result and 10 NTU lot number on the calibration log.
16. If the calibration solution of 10 NTU does not pass verification repeat the "StablCal®". If the meter repeatedly fails verification use a different meter.

CALIBRATION PROCEDURE (LaMotte 2020 or similar or as site Work Plan specifies):
Field personnel will check the calibration of field instrumentation consistent with the manufacturer's specifications and the following requirements before sampling:

1. The meter is calibrated daily (at a minimum) prior to field use, and calibration check is conducted after each calibration and at the end of day.
2. Gather the necessary calibration solutions included in the case. Invert each calibration solution 10 times.

3. Wipe the tube of selected calibration solution clean. It is important to use the proper test tubes and to assure the tubes are clean and free from fingerprints, lint, dried spills and significant scratches. A mild detergent may be used to remove dirt or fingerprints. Use lint free tissues to wipe your tubes clean.
4. Open the lid of the meter. Align the indexing arrow mark on the tube with the indexing arrow mark on the meter and insert the tube into the chamber.
5. Close the lid. Push the Read button. If the displayed value is not the same as the value of the selected standard (within the specification limits) continue with the calibration procedure.
6. Push the Cal button for 5 seconds until Cal is displayed. Release button. The display will flash. Adjust the display with the Up and Down buttons until the value of the standard is displayed.
7. Push the Cal button again to save the calibration. The 2020 display will stop flashing. Record all calibration results and calibration lot numbers on the calibration log.
8. Repeat steps 3-7 with the second calibration standard.
9. To perform the post calibration check, use the 10 NTU standard. Align the indexing arrow mark on the tube with the indexing arrow mark on the meter and insert the tube into the chamber.
10. Push the Read button.
17. Record the verification result and 10 NTU lot number on the calibration log.
11. If the calibration solution of 10 NTU is outside the ±10% acceptance range (9 – 11 NTU) re-calibrate the meter.

CALIBRATION CHECK:

An initial calibration will be conducted at the start of each day prior to sampling the groundwater. Calibration checks will be performed after the initial calibration and as needed by site-specific sampling procedures. If the instrument fails the calibration check (value falls outside 10% range), then the instrument will be calibrated again. The calibration check for the Hach 2100Q and LaMotte 2020 meters will be performed with the 10 NTU standard (acceptance criteria range: 9-11). The calibration check for the YSI 6820 and 6920 will be performed with the 126 NTU standard (acceptance criteria range: 113.4 - 138.6) or the 12.7 NTU standard (acceptance criteria range: 11.4-14.0), if provided. Initial calibrations and calibration check data will be recorded on the field calibration record provided in Attachment B.

Approval Signatures		
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Quality Assurance Officer		Date:

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SOG #NJ5

STANDARD OPERATING GUIDELINE FOR pH CALIBRATION

Geosyntec NJDEP Lab Certification Number: 11022

DATE PREPARED: 12/13/05

DATE REVISED: 04/24/18

SUMMARY:
This is the Standard Operating Guideline (SOG) to be used for the determination of pH in groundwater. This procedure is to be performed by qualified analysts in the field using rented field equipment. The owner of the equipment is responsible for its general care and maintenance. The analyst using this equipment in the field is responsible for calibration and inspection for potential defects in the equipment. Defective equipment will be returned to the owner and replaced with a new rental. Calibration procedures are to be conducted on the site where the groundwater is to be measured prior to the commencement of groundwater sampling.

EQUIPMENT:
YSI 650MDS with YSI 600 XL/XLM, 6920, or 6820 sonde; YSI 556; or equivalent

METHOD REFERENCE:
Standard Methods for the Examination of Water and Wastewater 4500-H B-11

MAINTENANCE:
Regular maintenance is to be conducted as specified by the manufacturer and owner of equipment. If defects are found in equipment during use, it will be returned to the owner. Equipment shall be inspected for defects upon receipt, prior to calibration, and periodically during sampling. If there is any indication that the equipment is broken or malfunctioning, it will be replaced or returned to the rental company for replacement.

The YSI sonde and probes will be cleaned prior to calibration and use by rinsing with distilled/deionized (DI) water. If contamination or particulate matter is present, a mild detergent will also be used (i.e. alconox).

CALIBRATION STANDARDS (or as specified by site specific Work Plan):
A three-point calibration using pH (4, 7, and 10 standard solutions) must be conducted. pH standard solutions of 4,7, and 10 will be provided by the equipment supplier. The identification numbers of the standard solutions will be recorded.

CALIBRATION PROCEDURE (or as specified in site-specific NJDEP approved Work Plan):
Field personnel will check the calibration of field probes consistent with the manufacturer's specifications and the following requirements before sampling:

INITIAL CALIBRATION

1. Meter calibration will be performed at the beginning of each day of use.
2. Turn the display unit on by pressing the green power button.
3. Use the arrow buttons to highlight Sonde Menu and press enter.
4. Select Calibrate and press enter.
5. Select pH and press enter.
6. Select the number of calibration points, 3, and press enter (the pH probe will be calibrated using three points (pH = 4,7, and 10)).
7. The screen will read, "Enter 1st pH". Starting with the 4.0 pH buffer, check the temperature correction chart, located below and on the calibration form, and find the value that corresponds with the current temperature of the buffer solutions. Enter this number on the screen. Example: if the buffer solution is at 30C, the temperature corrected value is 4.01. 4.01 should be entered on the screen.
8. Press enter (the pH 4 solution will be placed in the calibration cup first).
9. Observe the pH and temperature readings. When they are stable, press enter. The top of the screen will read, "calibrated".
10. Ensure that the calibrated reading is within **0.05** pH units of the standard (when calibrating to pH 4, a range of 3.95-4.05 is acceptable). If the reading is not accurate to within **0.05** pH units then restart the calibration procedure.
11. Record all calibration results on the calibration log.
12. Press enter once.
13. Remove the probe from the pH 4 solution.
14. Rinse the probes with DI water and gently dry them with a paper towel.
15. The screen will read, "Enter 2nd pH".
16. Type in your second pH point, for pH buffer 7, using the value from the temperature correction chart. Press enter.
17. Submerge the probes in the pH 7 solution.
18. Observe the pH and temperature readings. When they are stable, press enter. The top of the screen will read, "calibrated".
19. Ensure that the calibrated reading is within **0.05** pH units of the standard (when calibrating to pH 7, a range of 6.95-7.05 is acceptable). If the reading is not accurate to within **0..05** pH units then restart the calibration procedure.
20. Record all calibration results on the calibration log.
21. Remove the probes from the pH 7 solution.
22. Rinse the probes with DI water and gently dry them with a paper towel.
23. The screen will read, "Enter 3rd pH".

24. Type in your third pH point, for pH buffer 10, using the value from the temperature correction chart. Press enter.
25. Submerge the probes in the pH 10 solution.
26. Observe the pH and temperature readings. When they are stable, press enter. The top of the screen will read, "calibrated".
27. Ensure that the calibrated reading is within **0.05** pH units of the standard (when calibrating to pH 10, a range of 9.95-10.05 is acceptable). If the reading is not accurate to within **0.05** pH units then restart the calibration procedure.
28. Record all calibration results on the calibration log.
29. Remove the probes from the pH10 solution.
30. Rinse the probes with DI water and gently dry them with a paper towel.
31. On the Sonde main screen, highlight Sonde Run and press Enter.
32. Submerge the probes in the pH 7 solution.
33. Observe the pH and temperature readings. When they are stable, ensure that the pH reading is within **0.1** pH units of 7.0 (a range of 6.9-7.1 is acceptable).
34. Record all calibration results on the calibration log.

Temperature Dependence for pH Buffers

	10°C	**15°C**	**20°C**	**25°C**	**30°C**	**35°C**	**40°C**	**45°C**	**50°C**
pH Buffer 4.0	4.00	4.00	4.00	4.00	4.01	4.02	4.03	4.04	4.06
pH Buffer 7.0	7.06	7.04	7.02	7.00	6.99	6.98	6.98	6.97	6.97
pH Buffer 10.0	10.17	10.11	10.05	10.00	9.95	9.91	9.87	9.84	9.81

THREE HOUR CALIBRATION CHECK

Field personnel will perform a calibration check of the YSI's pH meter anytime it is used for longer than a three-hour period.

1. Turn the display unit on by pressing the green power button.
2. Use the arrow buttons to highlight Sonde Run and press enter.
3. Select the pH buffer value closest to the observed pH values at the current site.
4. Submerge the probes in the selected pH buffer solution.
5. Observe the pH and temperature readings. When they are stable, ensure that the pH reading is within **0.2** pH units of the buffer value. If the reading is not accurate to within **0.2** pH units then perform a calibration of the instrument's pH meter following the steps provided in the "initial calibration section" of this document.
6. Record all calibration results on the calibration log.

END OF DAY CALIBRATION CHECK:

In addition to performing a calibration check after three hours of meter use, a calibration check is to be performed at the end of each day of use. Field personnel should follow the procedures outlined in the "Three Hour Calibration Check" Section when performing the end of day check.

DAILY DUPLICATE

When conducting analysis other than low-flow sampling, a daily duplicate must be taken for pH, specific conductance, and DO measurements at a rate of 1 per 20 measurements. The daily duplicate should be taken within 15 minutes of the field reading and recorded on the DFR or on the form being used for recording the water quality measurements. For pH, the probe should be removed after taking the initial reading, rinsed with DI water, and then the duplicate reading should be taken. The acceptance range for pH is within ±.1 SU.

NOTE:

A calibration of pH must always occur when a calibration of oxidation-reduction potential (ORP) has been conducted and vice versa.

Approval Signatures		
Manager/Lead Technical Director		Date:
Quality Assurance Officer		Date:

STANDARD OPERATING PROCEDURE NO. 100

WATER LEVEL MEASUREMENT PROCEDURES

Prepared by:_____ Date:_9 February 2007_____

Reviewed by:_____ Date:_12 February 2007_____

Approved by:_____ Date:_13 February 2007_____

SOP No. 100

TABLE OF CONTENTS

Section **Page**

1. INTRODUCTION 1

    1.1 Overview 1

    1.2 Objective 1

    1.3 Equipment 2

2. PROCEDURES 2

STANDARD OPERATING PROCEDURE NO. 100
WATER LEVEL MEASUREMENT PROCEDURES

1. INTRODUCTION

1.1 Overview

This Standard Operating Procedure (SOP) was prepared to direct field personnel in the methods for conducting water level measurements in monitoring wells during field investigations at hazardous and non-hazardous waste sites. A water level measurement form is provided with this SOP.

This SOP will be implemented in accordance with the following governing documents:

- RI/FS Work Plan, which provides an overview of the site background and conceptual model and describes the overall investigative goals and scope of work for the RI/FS;
- Health and Safety Plan (HASP), which identifies all physical, chemical, and biological hazards relevant to each field task and provides hazard mitigators to address these hazards;
- Field Sampling Plan (FSP), which provides details for field sampling locations and procedures and which will be most frequently used by field staff on-site; and
- Quality Assurance Project Plan (QAPP), which is written to establish protocols necessary to ensure that the data generated are of a quality sufficient to ensure that valid conclusions are drawn from the site characterization.

1.2 Objective

The objective of water level measurements is to gain accurate measurements (to within 0.01 ft) of the depth of groundwater for use during well installation, potentiometric mapping, purge volume calculations during groundwater sampling, slug tests, packer tests, and pump tests.

1.3 Equipment

The following items of equipment will be used during water level measurements.

- graduated electronic water level indicator;
- tap water;
- Alconox®, Liquinox®, or other non-phosphate concentrated laboratory-grade detergent;
- deionized water;
- pump sprayer or pint squeeze bottles;
- Personal Protective Equipment (PPE), as required by HASP; for contaminated sites, one pair of gloves per well/piezometer;
- air monitoring equipment as required by HASP;
- field log book and water level measurement form as dictated by FSP;
- well keys; and
- oil/water interface probe, if non-aqueous phase liquid (NAPL) suspected.

2. PROCEDURES

The following procedures will be followed during water level measurements.

1. Fill one squeeze bottle or sprayer with detergent/water solution and a second with deionized water.
2. Record the condition of the well (protective casing, concrete collar, lock in place etc.) in the field log book or water level measurement form.
3. Check that the water level tape has no obvious kinks or damage.
4. Don PPE per the HASP, including a new set of gloves for each well. Stand upwind of the well; unlock and open the well. If a vented cap is present, conduct well mouth air monitoring from the vent per the HASP. If a non-vented well cap is present, remove the cap and monitor the well mouth immediately.

Record all pertinent air monitoring results (sustained, dissipating, background, odor).

5. Identify the previous measuring point marking or notch on the riser or casing (if present). Record this location in the field log book or on the water level measurement form.

6. Using a previously decontaminated water level indicator, turn on the meter, check the audible indicator, reel the electronic probe into the well riser (with the increments visible) slowly until the meter sounds, grasp the tape with hand, withdraw the tape and lower it again slowly until the sound is again audible. Check the depth to water on the tape and make a mental note of the depth to within 0.01-ft. Lower the probe again slowly and repeat the measurement for accuracy. A one-ft error is the most common measurement type during water level measurements. Be sure to read the depth correctly on the tape.

7. Record the depth to water from the measuring point and the measurement time in the field log book or on the water level measurement form.

8. If it is necessary to identify NAPL, this SOP will be modified to include the use of the oil/water interface probe. The procedures during the use of this probe should be implemented similarly and per the manufacturers' specifications. Through the use of this probe, product thickness can be determined.

9. Decontaminate the probe, the portion of tape that was submerged, and any obviously soiled tape. Wipe the probe with a paper towel soaked in detergent solution, followed by rinsing by spraying the probe with deionized water. Next, wipe the affected portion of the tape with a paper towel soaked in detergent solution followed by a paper towel soaked in deionized water.

Written by: Lauren Wellborn Date: 2/24/2014
Reviewed by Task Manager: Danielle Thorson Date: 11/15/2014
Reviewed by QA Manager: Julia K. Caprio Date: 11/17/2014

STANDARD OPERATING PROCEDURE NO. 101
FIELD DOCUMENTATION, SAMPLE DESIGNATION, CUSTODY AND HANDLING PROCEDURES

SECTION 1 INTRODUCTION

1.1 Objective

The objective of this standard operating procedure (SOP) is to maintain the integrity of each sample from the time of collection to the point of data reporting must be maintained throughout the study. Proper record keeping will be implemented in the field to allow samples to be traced from collection to final disposition. All information relevant to field operations must be properly documented to ensure that activities are accounted for and can be reconstructed from written records. Several types of logbooks will be used for this purpose and should be consistently used by field crews (e.g., field logbooks, field data sheets). This document describes the procedures to be followed for field documentation, sample designation, handling, and custody.

1.2 Referenced Documents and SOPs

- Health and Safety Plan (HASP),
- Quality Assurance Project Plan (QAPP)
- SOP 102 Procedure to Prepare Samples for Shipment

SECTION 2 FIELD DOCUMENTATION

2.1 Field Documentation

During field sampling events, field logbooks and field data sheets are used to record all daily field activities. The purpose of the field logbook is to document events that occur and record data measured in the field.

Data entry will be made in a bound, waterproof field logbook with consecutively numbered pages using indelible ink for each sampling event; all entries will be signed and dated and no erasures will be made. All corrections should consist of a single line-out deletion, followed by the sampler's initials and the date. The sampler will sign and date the last page at the end of each day, and a line will be drawn through the remainder of the page.

The project name, site name and location, and dates of sampling activity should be written on the cover of the field logbook. If more than one logbook is used during a single sampling event, then the upper right hand corner of the logbook will be annotated (e.g., 1 of 2, 2 of 2) to indicate the number of logbooks used during the field event. Alternatively, multiple logbooks could be used for different sampling activities (e.g., one logbook for surface water sampling and one for groundwater sampling). When multiple logbooks are used for a single sampling activity (e.g., 2 or more sampling teams operating simultaneously during a single surface water sampling event) logbooks should be annotated alphabetically to indicate which of those books is the primary, secondary, etc. logbook for that sampling activity, followed by the number of the logbook. For example, if surface water sampling requires 3 teams and each have a logbook to record daily activity over the sampling event then the primary book will be labeled "Log Book A-1" and the others as "B-1" and "C-1." When only one team is on site, they will use the primary (A) logbook. Field logbooks will be stored in a secure manner when not in use in the field.

In addition to the field logbook, supplementary field data forms may be used during a field sampling event to record the relevant information (e.g. field calibration forms, groundwater monitoring form). At a minimum, the sampler will record the following information daily in the field logbook or on a field sampling form, as applicable:

- Project name, project location, project number and daily objective;
- Project start date and end date;
- Date and time of entry (24-hour clock);
- Time and duration of daily sampling activities;
- Weather conditions at the beginning of the field work and any changes that occur throughout the day, including the approximate time of the change;
- Name of person making entries and other field personnel, including the times that they are present;
- Onsite visitors, if any, including the times that they are present;
- The name, agency, and telephone number of any field contacts;
- The sample number and analysis code for each sample to be submitted for laboratory analysis ;
- All field measurements made, including the time that the measurement was collected;
- The sampling location name, date, gear, water depth (if applicable), and sampling location coordinates;
- Type of sample gear used (e.g., pump type or model, gill net mesh size, size of core barrel);
- The location and description of the work area, including sketches and map references, if appropriate;

- Specific information on each type of sampling activity;
- The sample type (i.e., groundwater, soil, surface sediment), and sample number;
- Cross-references of numbers for duplicate samples;
- A description of the sample (source and appearance, such as soil or sediment type, color, and odor);
- Log of photographs (number taken, photo number on roll or memory card, brief description of photo) taken at the sampling location, if any;
- Variations, if any, from specified sampling protocols and reasons for deviation;
- References to other logbooks used to record information (e.g., field data sheets, health and safety log); and
- The signature of the person making the entry.

Monitoring or sampling equipment information, including installation information, any maintenance performed on each piece of equipment, calibration information, and other observations relating to the operation or condition of the equipment, will be recorded on field forms, in field logbooks, and/or in a separate field logbook maintained for a specific type of monitoring or sampling equipment. Upon completion of the field sampling event, the field team leader will be responsible for submitting all field logbooks and field data forms to the project data manager to be copied. Hard copy and an electronic copy shall be maintained in the project files.

SECTION 3 SAMPLE DESIGNATION AND HANDLING

3.1 Sample Labels

A self-adhesive, non-removable label will be affixed to each sample container and completed with an indelible marker prior to sample collection. Sample labels will contain the following information:

- Site name;
- Project number;
- A unique sample identification number (see QAPP for correct sample designation nomenclature);
- Initials of sample collector(s);
- Time and date collected;
- Analysis required; and
- Sample preservative (if applicable).

If samples are likely to contain high concentrations of VOCs or other analytes, the samples will be identified on the chain-of custody forms. Field duplicate or replicate samples will require special procedures for sample designation to ensure that they are submitted as blind samples to the laboratory. The well identification or sample location will not be included in the sample identification number and the collection time will be left blank but recorded in the field log book. The sample and corresponding field QC sample information will be documented in the field records.

3.2 Sample Handling

Each sample container will be sealed in a separate plastic bag following collection. Samples will then be stored in an insulated cooler containing ice packs or ice sealed in a plastic bag. If samples are not immediately shipped to the laboratory, they may be stored in a secure refrigerator/freezer and maintained at the proper temperature. Samples selected for laboratory analysis will be transferred to insulated coolers for overnight shipment to the laboratory. All samples shipped will be carefully checked against the chain-of-custody form (discussed below). Each cooler will be packed in a manner that will prevent damage to sample containers during shipment in accordance with SOP 102.

3.3 Sample Custody and Documentation

Chain-of-custody forms will be used to trace the possession and handling of all samples, from their collection, through analysis, until their final disposition. These forms will document the names of the relinquishing and receiving parties, the time and date of the transfer of custody, and the reason for the transfer of custody. One chain-of-custody form will accompany each cooler shipped to the laboratory. In the event that multiple coolers of samples are being sent to the same location, a unique, task specific, sample shipment group identifier and the number of coolers will be added to the top and special instructions portions of each chain-of-custody. The identifier will include the sample task (e.g., SW for surface water, SED for sediment), sample shipment group (SSG), date (year followed by day of year), and cooler destination (e.g., PITT for Test America Pittsburgh, NC for Test America North Canton). The chain-of-custody form will be placed in a sealed plastic bag inside the cooler. A custody seal will be placed on each cooler after packing and prior to shipment. For multiple cooler shipments, the sample shipment group identifier listed on the chain-of-custody will be written on the custody seal, as well as the cooler number designation (e.g., cooler 1 of 2, cooler 2 of 2). Shipping of samples to the laboratory will be accomplished by Federal Express or equivalent overnight service. Samples will remain in the custody of the sampling team until custody is relinquished to the courier service that will transfer the samples to the laboratory. Each sample shipment will be tracked via the courier weigh bill number to ensure that prompt delivery of the shipment to the laboratory has occurred.

Upon receipt by the laboratory sample custodian, the Sample Custodian will note on the form whether the custody seal is intact, the cooler temperature, the presence of air bubbles in any of

the water samples submitted for VOC analysis, any damaged sample containers and/or discrepancies between the sample label and information on the form, and sign and date the form. A copy of the chain-of-custody form will then be transmitted to the Project Manager or their designate for their records.

Written by: Lauren Wellborn Date: 2/24/2014
Reviewed by Task Manager: Danielle Thorson Date: 11/15/2014
Reviewed by QA Manager: Julia K. Caprio Date: 11/17/2014

STANDARD OPERATING PROCEDURE NO. 104
MANAGEMENT AND DISPOSAL OF INVESTIGATION DERIVED WASTE

SECTION 1 INTRODUCTION

This Standard Operating Procedure (SOP) establishes protocols for testing, storage, and disposal of Investigative Derived Waste (IDW). Disposal of laboratory test equipment and supplies will be handled in accordance with the laboratory QAPP.

1.1 Objective

IDW generated during this RI/FS may include:

- Sediments
- Surface water
- Photoionization Detector/Flame Ionization Detector (PID/FID)
- Personal Protective Equipment (PPE)
- Disposable sampling equipment
- Spent decontamination liquids
- Plastic sheeting, containers, etc.

The management of these IDW will be conducted to limit exposure of site personnel to hazardous materials and to prevent introduction of contaminated materials to uncontaminated environmental media at the site.

1.2 Referenced Documents and SOPs

- Health and Safety Plan (HASP)
- Quality Assurance Project Plan (QAPP)

SECTION 2 GENERAL MEDIA

All IDW identified as potentially contaminated with hazardous materials, including NAPL, will be collected at the point of generation and later stored in a designated and clearly marked IDW management area. All containers/drums will also be clearly labeled to indicate the source of the IDW. The IDW storage area will be inspected daily to ensure that storage procedures are adequate to keep the IDW isolated and contained. Potentially contaminated IDW will be identified based on its origin and olfactory and visual evidence (e.g., presence of NAPL). Laboratory testing will be required to determine the proper disposition of these IDW.

The volume of waste will be minimized whenever applicable. Soil, sediment, liquid, and personal PPE IDW will be segregated and separately containerized. The PPE and plastic sheeting will be disposed of as nonhazardous waste unless it has been grossly contaminated. Spent decontamination liquids will be containerized in drums and tested to determine the proper disposal method.

SECTION 3 SURFACE WATER

Surface water waste may be generated as excess sample material. The required testing and handling of these IDWs will depend on their origin and characteristics. Olfactory, visual observations, and field screening with PID/FID will be used to determine if the surface waters contain potentially elevated levels of hazardous materials. Based on previous site investigations, surface waters are anticipated to not meet the characteristics of hazardous waste. Therefore, unless field observations indicate otherwise, excess sample volumes will be disposed of at the point and time of collection back to the water body.

SECTION 4 SEDIMENTS

Waste sediments will be generated as excess sample material. The required testing and handling of these IDWs will depend on their origin and characteristics. Olfactory, visual observations, and field screening with PID/FID will be used to determine if the sediments contain potentially elevated levels of contaminants of potential concern (COPC) and direct where confirmation samples will be collected for hazardous waste characterization per the QAPP. It is anticipated that sediments meeting the characteristics of hazardous waste will be encountered. Therefore, as dictated by field measurements, excess sample material will be collected at the point of generation and later stored in a designated and clearly marked IDW management area.

Written by: Amanda Hughes & Derek Tomlinson Date: 11/3/2014
Reviewed by Task Manager: Danielle Thorson Date: 11/15/2014
Reviewed by QA Manager: Julia K. Caprio Date: 11/17/2014

STANDARD OPERATING PROCEDURE NO. 106
WATER AND NAPL LEVEL MEASUREMENT PROCEDURES

SECTION 1 INTRODUCTION

This Standard Operating Procedure (SOP) was prepared to direct field personnel in the methods for conducting water level measurements and assessing non-aqueous phase liquid (NAPL) presence and quantity in monitoring wells during field investigations at hazardous and non-hazardous waste sites.

1.1 Objective

The objective of water level measurements is to gain accurate measurements (to within 0.01 ft) of the depth of ground water for use during well installation, in the recording of data for the preparation of ground water elevation contour maps, purge volume calculations during ground water sampling, slug tests, packer tests, and pump tests. Additionally, the objective of measuring the water/oil interface is to confirm NAPL presence, and estimate the quantity of NAPL present.

1.2 Reference Documents and SOPs

- SOP 103 Decontamination Procedure for Sampling Equipment

1.2 Equipment

The following list of equipment may be utilized during water level measurements. Site-specific conditions may warrant the use of additional or deletion of items from this list.

- electronic water level indicator or oil/water interface meter (graduated);
- tap Water;
- Alconox, liquinox or other non-phosphate concentrated laboratory grade soap;
- deionized Water;
- pump sprayer;
- pint squeeze bottles;
- any necessary personal protective equipment (gloves, eyewear, tyvek suits);
- air monitoring instruments as required (HNu, OVM, etc.);
- field logbook and applicable supplementary field data forms;
- well keys;

- previous measurement data (if available); and
- plunker on tape.

SECTION 2 PROCEDURES

The following procedures should be followed during water level measurements. Procedures utilized during water level measurements where non-aqueous phase liquids are present should be modified to include the use of the oil/water interface meter. When the objective is to record NAPL depth and/or thickness, an oil/water interface meter should be used. Procedures may vary depending on the equipment used and contaminants present at the site. As such, use of the oil/water interface meter or electronic water level indicator should adhere to the manufacturers' specifications. Site specific conditions may warrant the use of stringent air monitoring and potentially more significant decontamination scenarios.

1. Record the condition of the well (protective casing, concrete collar, lock in place etc.).
2. Check that the water level tape has no obvious kinks or damage.
3. Put on latex or other sterile gloves. Stand upwind of the well; unlock and open the well. If a vented cap is present, conduct well mouth air monitoring from the vent. If a non-vented well cap is present, remove the cap and monitor the well mouth immediately. Record all pertinent air monitoring results (sustained, dissipating, background, odor).
4. Identify the previous measuring point marking or notch on the riser or casing (if present). Record this location in the field logbook or on the applicable field form (e.g. water level monitoring form).
5. Using a previously decontaminated electronic oil/water interface meter or water level indicator, turn on the meter, check the audible indicator, reel the electronic probe into the well riser (with the increments visible) slowly until the meter sounds, grasp the tape with hand, withdraw the tape and lower it again slowly until the sound is again audible. Check the depth to water on the tape and make a mental note of the depth to within 0.01 feet. Lower the probe again slowly and repeat the measurement for accuracy. A one-foot error is the most common measurement type during water level measurements. Be sure to read the depth correctly on the tape.
6. Record the depth to water from the measuring point in the field logbook or on the applicable field form (e.g. water level monitoring form).
7. When using an oil/water interface probe to record NAPL depth and/or thickness advance the probe slowly until the audible indicator sound changes. Check the depth to water on the tape and make a mental note of the depth to within 0.01 feet. Lower the probe again slowly and repeat the measurement for accuracy. A one-foot error is the most common

measurement type during water level measurements. Be sure to read the depth correctly on the tape.

8. Repeat as necessary.
9. Decontaminate the probe and meter and any obviously soiled tape. Refer to SOP 103 equipment decontamination.

Written by: Danielle Thorson Date: 2/24/2014
Reviewed by: Mustafa Saadi Date: 11/20/2014
Reviewed by QA Manager: Julia K. Caprio Date: 11/17/2014

STANDARD OPERATING PROCEDURE NO. 107
SOIL DESCRIPTION: VISUAL - MANUAL PROCEDURE OF THE UNIFIED CLASSIFICATION SYSTEM

SECTION 1 INTRODUCTION

This Standard Operating Procedure (SOP) was prepared to direct field personnel in the method for describing soil samples in test pits, soil borings, and soil grab samples. The SOP conforms to ASTM Standard D2488, Standard Practice for Description and Identification of Soils (Visual-Manual Procedure) and other pertinent technical publications.

1.1 Objective

The objective of soil sample description is to provide geological information useful for the purpose of hydrogeological or geotechnical evaluation of a site.

1.2 Equipment

The following equipment may be necessary during soil description activities:

- sand grading chart
- field logbook and applicable supplementary field data forms
- pocket knife, spoon, small spatula
- folding ruler or yard stick
- portable table
- polyethylene sheeting
- hand lens
- deionized water in squeeze bottle
- required personal protective equipment (gloves, boot, eye wear, hard hat, etc.)
- air monitoring equipment (as required)

- duct tape
- boring logs (if applicable)
- small squirt bottle with dilute hydrochloric acid

SECTION 2 PROCEDURES

2.1 General Soil Description

The general description of a soil sample should be in the following order:

1. Color
2. Density
3. Moisture content
4. Geologic modifiers or classifications
5. Major Constituent - capitalized
6. Minor Constituent (s)
7. Geologic Description (in parentheses)

Example: Tan, loose, wet, stratified, medium SAND, little fine sand, trace coarse sand, trace silt (Till).

When logging a soil sample collected from a split spoon where more than one soil type is present, describe each one separately on the applicable field form (e.g. soil boring log). Start the description from the top of the split spoon, and log each change in stratigraphy in sequence to the bottom of the spoon. Provide an interval or length (i.e., 0-0.5 ft:) at the beginning of each separate sequence description, followed by a colon. Draw a line below the bottom of the complete sample description.

2.2 Color

The main color value should be stated, along with an appropriate modifier. For example

- light brown
- dark brown
- reddish brown
- brown

The presence of mottling should be included in the description, where present. For example:

- Gray, slightly mottled, dense, damp, poorly sorted angular fine to medium SAND, some silt, trace angular coarse sand, trace clay (lodgement glacial till).

2.3 Density

In borings, density should be based on the sum of the middle two 6-inch blow counts of a two-foot split spoon or the last two 6-inch blow counts of an 18-inch split spoon. Professional judgement should be used when applying the density modifier. If high blow counts are due to the presence of a cobble, boulder or large piece of gravel that impedes forward progress of the split spoon, density should based upon the character of the material in the split spoon, if any, or omitted from the description. A notation should be made in the sample description when this situation occurs. Appropriate modifiers are described in the following table.

Granular Soils		Cohesive Soils	
Blows/ft	**Density**	**Blows/ft**	**Density**
0-4	very loose	0-2	very soft
4-10	loose	2-4	soft
10-30	medium dense	4-8	medium stiff
30-50	dense	8-15	stiff
>50	very dense	15-30	very stiff
		>30	hard

In test pits, density is subjective and should be based upon the ease of excavation. The above adjectives for granular and cohesive soils should be used in the description.

2.4 Moisture Content

Moisture content should be described using the following modifiers:

- **Dry** - no moisture.
- **Damp**- very slight moisture content, no visible water droplets.
- **Moist** - very slight moisture content, soils will not stick together.
- **Wet** – enough moisture for soils to stick together.
- **Saturated** – water dripping from sample; soils below the water table.

2.5 Geologic Modifiers

Sedimentological descriptions aid in the geologic classification of a soil material. Only insert geologic modifiers when present.

Stratification

Note the presence and thickness of alternating layers of non-cohesive materials of different grain sizes and/or color with layers ***at least 6 mm*** thick.

Lamination or Varves

Note the presence and thickness of alternating very thin layers of fine materials or color, such as silt and clay, with layers ***less than 6 mm*** thick.

Sorting

A geological term used to describe how close in size the grains in a sample are to each other. For example, a well sorted sample contains grains of similar size; a poorly sorted sample contains grains of many sizes.

Grading

An engineering term used to describe the range in grain sizes present in a sample. For example, a narrowly graded sample contains grains of similar size; a widely graded sample contains grains of different sizes.

Angularity or Rounding

Geological terms that are used to describe the general appearance of visible grains in the soil sample. Useful in determining the origin and depositional environment of a material. Water transported materials may be rounded. Glacial tills will be more angular.

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

Shape

A term used to describe the shape of gravel, cobbles, and boulders. Terms are as follows where the particle shape shall be described where the length, width, and thickness refer to the greatest, intermediate, and least dimensions of a particle.

- **Flat** – Particles with width/thickness > 3.
- **Elongated –** Particles with length/width > 3.
- **Flat and Elongated –** Particles meet criteria for both flat and elongated.

Odor

Describe the odor if organic or unusual. Soils containing a significant amount of organic material have a distinct odor of decaying vegetation. Always utilize appropriate breathing zone air monitoring equipment as specified in the site specific health and safety plan.

Hydrochloric Acid Reaction

As appropriate for the geologic environment, describe the reaction with hydrochloric acid (HCL) as none, weak, or strong. As calcium carbonate is a common cementing agent, a report of its presence on the basis of the reaction with dilute hydrochloric acid is appropriate for certain projects.

- **None –** No visible reaction.
- **Weak –** Some reaction, with bubbles forming slowly.
- **Strong –** Violent reaction, with bubbles forming immediately.

Cementation

Describe the cementation of intact coarse-grained soils as follows.

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

Identification of Peat

A sample composed primarily of vegetable tissue in various stages of decomposition that has a fibrous to amorphous texture, usually a dark brown to black color, and an organic odor. When present the sample shall be designated as highly organic soil.

2.6 Major/Minor Constituents

Grain-size scales

Grain size classification should be based on an accepted classification system such as, the Unified Soil Classification System. The predominant grain size should be listed in the soil description in all capital letters.

Boulder	> 300 mm

Cobble:	75 - 300 mm
C. Gravel:	19 - 75 mm
F. Gravel:	4.75 - 19 mm
C. Sand:	2.0 - 4.75 mm
M. Sand:	0.425 - 2.0 mm
F. Sand:	0.075 - 0.425 mm
Silt:	0.002 - 0.075 mm
Clay:	<0.002 mm

Proportions

For geologic description, proportions of grain sizes will be based upon the following nomenclature:

- Trace: 0-10%
- Little: 10-20%
- Some: 20-35%
- And: 35-50%

The major soil sample constituent is always capitalized and listed first.

Minor constituents also include ancillary materials such as mica flakes, dark minerals, or naturally occurring organic matter, such as humus, peat, or other vegetative material.

Geologic Description

Where possible based on existing site data, local research, or geologic understanding of the local region, include a geologic description of the sample. Examples include till, fluvial, glaciofluvial, fill material, Lowell Formation. Do not utilize geologic description if not certain.

Written by: Amanda Hughes Date: 11/3/2014
Reviewed by Task Manager: Danielle Thorson Date: 11/15/2014
Reviewed by QA Manager: Julia K. Caprio Date: 11/17/2014
Updated by: Leanne Wiskemann Date: 8/19/2019
Reviewed by Laboratory Manager: Jessica Evans Date: 12/19/2019

STANDARD OPERATING PROCEDURE NO. 108
COLLECTION OF GROUNDWATER SAMPLES

SECTION 1 INTRODUCTION

This Standard Operating Procedure (SOP) was prepared to provide instructions for groundwater sampling using the USEPA low-flow with minimal drawdown well purging protocol and sampling with a bailer when non-aqueous phase liquid (NAPL) is present.

1.1 Objective

The objective of groundwater sampling is to obtain a representative sample of groundwater for laboratory analysis of contaminants of concern at a given site. This objective requires that the sample be both free of unsuitable material and be of sufficient quantity and quality for analysis by the selected analytical method.

1.2 Referenced Documents and SOPs

- Health and Safety Plan (HASP)
- Plus and Barcelona (1996). Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures. *EPA Ground Water Issue*. EPA/540/S-95/504
- Quality Assurance Project Plan (QAPP)
- SOP 100 Recording Sample Location with a GPS
- SOP 101 Field Documentation, Sample Designation, Custody and Handling
- SOP 102 Procedure to Prepare Samples for Shipment
- SOP 103 Decontamination Procedure for Sampling Equipment
- SOP 104 Management and Disposal of Investigative Derived Waste
- SOP 110 Water Level Measurement Procedure
- SOP 124 Procedure to Calibrate Field Instrument
- USEPA Method 1669 (USEPA, 1996)

1.3 Equipment

1.3.1 Documentation

- field log forms and applicable supplementary field data forms;
- writing tools (pencils, Sharpie®, etc.);
- bottle labels;
- equipment manuals;
- field calibration forms;
- analysis and sample bottle summary;
- digital camera;
- water proof field log book; and
- mapping-grade GPS, as described in SOP 100, for recording sample locations or navigating to pre-determined locations.

1.3.2 Storm Gear

- rain gear (i.e., boots, ponchos); and
- flashlights (preferably head flashlight) or work-place lights.

1.3.3 Task-Specific Equipment

- boots, waders, and other personal protective equipment (PPE) as required by HASP;
- gloves: clean, non-talc nitrile;
- water level tape;
- water quality Sondes (YSI 6-series) with flow-through cell and probes for measuring field parameters;
- spare batteries for equipment;
- interface meter;
- instrumentation and calibration solutions for field probes;
- decontamination equipment (see SOP 103);
- laboratory-supplied reagent grade water for blank samples (note that different analytical groups may require water prepared and certified by the laboratory to different standards from other analytical groups [i.e., reagent water supplied for trace metals analysis blanks will need to be certified to lower levels of metals than that for regular metals analysis]);
- sample containers and preservatives (analysis-dependent, see QAPP);
- 0.45-µm, high-capacity water sample filters;

- Teflon-lined tubing, connections, and tools, as appropriate; sufficient tubing to dedicate to each well;
- graduated cylinder or 1-liter bottle and stopwatch;
- 5-gallon bucket and funnel for purge water;
- large crocodile clip to steady hosing;
- sorbent pads;
- cable ties;
- hand tools (Allen wrench set, hammer, screwdrivers, pliers, knife, wire strippers, measuring tape);
- labels for drums of purged groundwater;
- paper towels;
- Zip-lock bags;
- trash bags (one for IDW and one for general trash);
- clean plastic sheeting;
- marine vessel;
- wooden stakes and highly visible spray paint;
- peristaltic, bladder, submersible, or Waterra pump capable of a flow rate between 50 and 500 mL/minute and appropriate power supply, including compressor if needed. The pump type will principally depend on the depth to water and well diameter. Bladder or submersible pumps are preferred, peristaltic pumps are acceptable only for wells where the depth to water is less than approximately 25 feet. Waterra pumps are only recommended for narrow diameter wells that cannot be sampled using a bladder or peristaltic pump;
- bottom-filling Teflon™ bailer;
- SEBS resin tubing – provided by the analytical laboratory and certified as meeting the requirements of USEPA Method 1669 and double bagged;
- fluoropolymer tubing – provided by the analytical laboratory and certified as meeting the requirements of USEPA Method 1669 and double bagged (if using peristaltic pump);
- battery and spare battery to power pump;
- battery charger;
- coolers;
- ice; and
- voltmeter for trouble-shooting peristaltic pump malfunction.

SECTION 2 PROCEDURES

2.1 Pre-Mobilization Activities

1. Obtain the construction, diameter, depth, material, screened interval, and map showing location for each monitoring well to be sampled.
2. Obtain a listing of the parameters that will be measured in the field or laboratory as part of this sampling program including the required analytical method, analytical lab, sample volume, nomenclature, preservative, sample containers and holding time for each parameter as detailed in the QAPP. The parameters that will be measured in the field are the low-flow stabilization parameters including temperature, pH, salinity, specific conductance, oxidation reduction potential (ORP), dissolved oxygen (DO), and turbidity. These parameters will be recorded during low flow purging and immediately prior to collection of samples for laboratory analysis. In addition, certain geochemical parameters, such as ferrous iron, may be measured in the field through test kits. Remaining parameters will be measured in the laboratory.
3. Obtain a listing of the frequency of the applicable field quality control (QC) samples; duplicates, MS/MSD pairs, field blanks, equipment blanks and trip blanks sampling as per the QAPP.
4. Verify that all equipment on order is being shipped to the site.
5. Make contact with state underground utilities location services (811) to seek approval for any new intrusion into the subsurface.

2.1.1 Sample Container and Tubing Preparation

1. Sample container procurement should be arranged with the analytical laboratory several weeks prior to the event. Pre-label containers where possible.
2. Field equipment that must be cleaned and provided by a supplier should be ordered several weeks prior to the event.
3. Upon receipt of the cleaned sample bottles from the laboratories, bottles should be inventoried.
4. Equipment blanks should be collected from the tubing provided by the analytical lab if applicable.
5. Powder-free nitrile gloves should be worn whenever handling clean bottles.
6. Containers shall be placed in clean coolers for transport to the field.

2.2 Pre-Sampling Procedures

Several steps are required before sampling any of the wells. These steps ensure that instruments are functioning and properly calibrated and that the necessary equipment has been supplied for efficient and accurate sampling.

2.2.1 Inventory

Verify that the correct equipment has been received by the field site and that it is clean (decontaminated). Inventory sample containers to verify that the laboratory has provided the correct number of containers of the proper size and containing the correct preservative if required. To the extent possible, pre-label/tag and bundle sample containers for each well to avoid confusion during sample collection.

Verify that the appropriate PPE and ancillary supplies (e.g., paper towels, decontamination solution) have been received by the field site. The appropriate protective equipment, as specified in the HASP, will be reviewed during a morning tailgate meeting. Contact the field manager or project manager immediately if there are discrepancies.

2.2.2 Calibration

Calibrate the multi-parameter sonde consistent with the manufacturer's specifications before sampling and at the start of each field day. A check of the calibration shall be performed at least once more during the field day. Instruments will be recalibrated as necessary (e.g., when calibration checks indicate incorrect operation) to ensure accurate measurements, and all checks and recalibrations will be recorded on the applicable field form (e.g. field calibration form). Calibration will also be checked if any readings during sampling are suspect. Calibration procedures are described in SOP 124.

2.2.3 Well Inspection

Inspect the well for the presence of lock and cap, surface seal integrity, obstructions, evidence of tampering, debris, or surface water collecting in flush mounts. Note any irregularities in the applicable field form (e.g. groundwater sampling field form). If the well casing is damaged and there are anomalies in the calculated water level at the well, then the casing damage may indicate compromised sample quality.

2.3 <u>Well Purging and Sampling</u>

Sampling is performed in teams according to the health and safety protocol for the site. Under most tasks, sampling is performed using a five-step procedure that will be followed upon arrival at each well:

1. Set-up;
2. Purging;
3. Measurement of field parameters and field testing;
4. Sampling; and
5. Clean-up and decontamination.

Detailed procedures for performing each of these steps are provided in the following subsections.

2.3.1 Set-up

All necessary equipment for purging, sampling, and storage will be brought to the well before the well is opened. Equipment will be placed on a clean plastic sheet near the well. General parameters describing the well and field condition (e.g., well identification, depth, weather, date, and time) will be documented on a field data sheet. PPE, as required by the HASP, will be donned prior to opening well. Sampling begins by opening the well and measuring the depth to the water table. The tubing, multi-parameter sonde, and reservoir for purged water are then set up.

2.3.2 Purging by Low Flow Protocol

Wells are purged using the low flow/minimum drawdown protocol as described by Puls and Barcelona (1996) and summarized below. The general procedural requirements for low-flow purging are listed below.

1. Lower the pump slowly down the well, positioning the pump intake at the middle of the well screen and tubing will be connected to a flow-through cell and a discharge line will be run from the flow-through cell to a bucket.
2. Minimize disturbance of the water column in the well by initiating pumping at a low rate (see below). Dedicated tubing (left in-place between sampling events) is also recommended to minimize disturbance to the water column before and during sampling.
3. Begin pumping at a steady rate of 100 mL/min and measure the depth to water frequently (e.g., every minute for the first few minutes) to ensure that less than 0.3 ft of drawdown occurs. The pumping rate may be increased if drawdown is less than 0.3 ft, but the pumping rate will not exceed 500 mL/min. In some silty and/or clayey formations, drawdown may exceed 0.3 ft when pumping at 100 mL/min. If this occurs, refer to Section 2.3.3 Variations from Low Flow Protocol, below, for alternatives to the low flow/minimum drawdown protocol.
4. Field parameters and depth to water will be recorded on field data sheets ~~a minimum of~~ every five minutes while purging or after initial purge, post-purge, and following sample collection. Purging will continue until temperature, pH, salinity, specific conductance, ORP, DO, and turbidity stabilize (three consecutive readings), which is defined as follows:

    - ±0.1 units for pH;
    - ±3% for specific conductance;
    - ±10% for salinity;
    - ±10 mV for ORP;
    - ±3% for temperature;

- ±10% for turbidity for values greater than 1 NTU; and
- ±10% for DO.

5. DO and turbidity tend to stabilize last and are better measures of sufficient purging.
6. In the case that the above criteria for stabilization are not met before three well volumes have been pumped, then a maximum of five well volumes will be pumped before samples are collected. In accordance with the NJDEP Field Sampling Procedures Manual and USEPA guidance "the following options are available if stability has not been achieved after FOUR hours of purging:
   - 1) continue purging until stabilization occurs, no matter how long it takes;
   - 2) discontinue purging, do not collect a sample and document the attempts to reach stabilization; or
   - 3) discontinue purging, collect a sample and document the attempts to reach stabilization."

2.3.3 Variations from Low Flow Protocol

Wells in low-yield formations such as silt or clay soils may not yield sufficient water for purging (e.g., 100 mL/min) without more than 0.3 ft of drawdown. In these cases, a modified low-flow method will be used. Currently, there is no published protocol for sampling low-recharge wells. Two modifications described below have been endorsed at one site by USEPA for sampling and purging wells that yield less than 100 mL/min at a drawdown of 0.3 ft.

Alternative Method 1: Less than half the casing volume is located above the well screen

Purge the well with the pump intake located at the midpoint of the well screen by constant pumping at a rate no greater than 500 mL/min until the water level reaches the top of the well screen. Measure and record the field parameters and water depth at a minimum of five-minute intervals or at the end of every purge cycle, although it may be difficult to obtain stable measurements of certain parameters (i.e., DO, ORP, turbidity). Cease pumping and allow the water level to recover until the standing water column in the well (length from water level to bottom of well) equilibrates to at least 90% of the static water column. Repeat the purging and cessation cycle until a minimum of one casing volume is removed from the well. The well will then be allowed to recover sufficient volume to collect the required groundwater sample from the midpoint of the screened interval, within 24 hours of the last purging event.

Alternative Method 2: More than half the casing volume is located above the well screen

The well will be purged with the pump intake located at midpoint of the well screen at a rate no greater than 500 mL/min until the water level reaches the top of the well screen. This will remove at least one-half of a casing volume of water from the well. The well is then allowed eight hours to recover, after which time a volume of water equal to the casing volume of the screened interval will be removed, removing approximately a full casing volume during the two purging events.

Directly following the second purging event, the required groundwater sample is to be collected from the midpoint of the screened interval.

Other Modifications to Low Flow Sampling

Other modifications of the low-flow protocol may be required. Low-recharge wells screened across the water table are not amenable to either of the methods described above. It may not be practical to sample extremely low recharge wells using any of the cited modifications, in which case, it will be necessary to evacuate all casing water and re-sample as soon as sufficient recharge has entered the well to provide a sample. A modified approach will be necessary for some of the work plans, as directed within those work plan elements. Data from such wells will be qualified to indicate the potential for sample bias.

2.3.4 Field Measurements

Field parameter measurements will be recorded following parameter stabilization (purging) and before sampling. The pumping rate and sampler intake location in the well are not to be adjusted after purging. The field parameters typically measured are temperature, pH, salinity, specific conductance, ORP, DO, and turbidity.

2.3.5 Sample Collection by Pump

Samples will be collected after field parameters have stabilized and measurements recorded. The pump rate and sample intake location will not be adjusted between purging and sampling. Samples are to be obtained from the influent line (prior) to the flow-through cell (i.e., field parameters cannot be measured during sampling). The following sampling strategy is to be followed at each location in its entirety prior to beginning a new location.

Additionally, all individuals involved in sample collection will be trained by a sampler experienced in the collection method prior to collection of samples.

Sample containers are to be filled in the order listed below as applicable to the task specific analytical program. Note that many sample containers contain preservatives; hence, it is necessary to fill each container carefully enough to avoid or minimize overfilling, which may dilute the preservative to unacceptable levels.

1. If collected, volatile organic compound (VOC) samples will be collected first. Sample containers are to be completely filled so that a positive meniscus forms over the opening of the container. The container lid will be moistened with groundwater and screwed to the container body. The container is then turned upside down and inspected for air bubbles. If air bubbles exist in the container, then it is “topped off” to eliminate bubbles. This procedure is repeated until there are no entrapped bubbles in the container. Filled samples are stored at 4°C but not frozen.
2. Then, if collected, the following samples are collected:

a) Total petroleum hydrocarbons (TPH) – water will be dispensed into two 1,000 mL amber glass bottles without preservative, sealed, and stored at 4°C but not frozen.

b) Polycyclic Aromatic Hydrocarbons (PAHs) – water will be dispensed into two 1,000 mL amber glass bottles without preservative, sealed, and stored at 4°C but not frozen.

c) Semi-volatile organic compound (SVOC) and Polycyclic Aromatic Hydrocarbons (PAH) – water will be dispensed into two 1,000 mL amber glass bottles without a preservative, sealed, and stored at 4°C but not frozen.

d) PCBs and pesticides - water will be dispensed into two 1,000 mL amber glass bottles without a preservative, sealed, and stored in dark conditions at 4°C but not frozen.

e) Metals – groundwater will be split into two portions; one filtered sample and one unfiltered sample. The filtered sample (for dissolved metals analysis) will be field-filtered using a clean, disposable, 0.45-µm filter attached in-line to the sample tubing. Filtered water will be dispensed into a 500 mL wide-mouth plastic bottle with HNO_3 as a preservative to achieve a pH below 2, sealed and stored at 4°C but not frozen. Unfiltered water (for total metals analysis) will be dispensed directly in to a 500 mL wide mouth plastic bottle with HNO_3 as a preservative to achieve a pH below 2, sealed, and stored at 4°C but not frozen.

3. If NAPL mobility characteristics are to be analyzed, the following analyses are to be performed:

a) Fluid Properties: Density via ASTM D1481, viscosity via ASTM D445, interfacial tension and surface tension via ASTM D971 at three different temperatures. These are used in understanding the potential for the NAPL to migrate. Water will be dispensed into a 250 mL glass bottle without a preservative, sealed, and stored at 4°C but not frozen.

b) OILPRINT™: This test follows IP method 318/75M and is a high-resolution chromatographic test for petroleum hydrocarbons (C4 to C35+) fingerprint analysis used for NAPL identification. The type of NAPL will also affect the ability for the NAPL to migrate. Analysis will be from the samples collected for fluid properties.

2.3.6 Sample Collection by Bailer

Groundwater samples collected from wells that are not purged and for which field measurements are not collected, the following procedure is prescribed:

1. Prior to sampling, sorbent pads will be placed around the well to capture potential drips from the sampling activities;

2. Slowly lower a decontaminated interface meter down the well to confirm NAPL presence. Collect and record water and NAPL level measurements according to procedures outlined in SOP 110;
3. Lower a clean, clear, dedicated bottom-filling Teflon™ bailer into the groundwater above the NAPL interface. Do not submerge the bailer. Collect a groundwater sample and slowly raise the bailer out of the well to avoid disturbing the NAPL and without touching the sidewalls to avoid contaminating the sample;
4. Transfer groundwater from bailer into appropriate sample containers as per the QAPP; and
5. Repeat groundwater sample collection until the desired volume for samples is achieved.

Sample containers are to be filled in the order provided in Section 2.3.5. Note that many sample containers contain preservatives; hence, it is necessary to fill each container carefully enough to avoid or minimize overfilling, which may dilute the preservative to unacceptable levels.

2.3.7 Observations During Sampling

Field sampling staff will identify and log any observations into a field notebook or in the applicable field form for each well. These observations include, but are not limited to: excessive bubbling within the tubing or in the sample containers as they are filled; odors such as sulfide; excessive turbidity, solids, or formation of precipitates in the samples; color changes in the water; and unusual sounds made by the equipment.

2.3.8 Storage and Shipping

All samples will be immediately placed on ice (preferably double-bagged wet ice packs) to remain at 4°C but not frozen prior to and during shipment to the laboratory. The sample containers will be stored in a cooler until further processing. Refer to the SOP 102 for sample shipping.

2.4 Sample Disposition

Samples will be labeled, maintained in custody, and handled in accordance with SOP 101. Samples shall be prepared for shipment in accordance with SOP 102.

2.5 Documentation

Activities conducted as part of this SOP shall be documented in accordance with SOP 101. Documentation shall include a record of daily conditions and activities, calibration activities, sampling activities, and all other information required to be recorded per SOP 101.

2.6 Decontamination Procedures

Equipment will be decontaminated between sample locations. Decontamination shall be performed according to SOP 103. Personnel and PPE decontamination shall be performed in accordance with the HASP.

2.7 Investigative Derived Waste (IDW)

IDW, including decontamination fluids, used PPE, and other IDWs generated during activities associated with this SOP shall be handled and disposed of according to SOP 104.

Written by: Amanda Hughes Date: 11/3/2014
Reviewed by Task Manager: Danielle Thorson Date: 11/15/2014
Reviewed by QA Manager: Julia K. Caprio Date: 11/17/2014

STANDARD OPERATING PROCEDURE NO. 110
PROCEDURE TO CALIBRATE FIELD INSTRUMENT

SECTION 1 INTRODUCTION

1.1 Objective

The objective of collecting *in situ* water quality and air quality data is to obtain representative physical/chemical parameters of the waterway being studied. This objective requires that the instrument be calibrated accurately. Therefore, this standard operating procedure (SOP) establishes procedures for calibrating a multiparameter water meter, and a photoionization detector/flame ionization detector (PID/FID).

1.2 Referenced Documents and SOPs

- Health and Safety Plan (HASP)
- Quality Assurance Project Plan (QAPP)
- SOP 103 Decontamination Procedure for Sampling Equipment

1.3 Task-Specific Equipment

- Boots, waders, and other personal protective equipment (PPE) as required by HASP;
- Water quality sondes (YSI 6-series);
- Stainless-steel weights;
- Sample containers;
- Coolers;
- Ice;
- Tape measure;
- Paper towels;
- Trash bags (one for IDW and one for general trash);
- Spare equipment batteries;
- Calibration solutions;

- Laptop computer (for data download, verification of proper data storage on the YSI, and direct data logging) with ECOWIN software; and
- Decontamination equipment (see SOP 103).

SECTION 2 PROCEDURES

2.1 Calibration of Water Quality Sonde

Water quality sondes are to be calibrated at the beginning of each sample day and checked for accuracy at the end of each sample day.

2.1.1 Daily Calibration

Water quality sondes shall be used to monitor *in situ* turbidity levels (in NTU), temperature, dissolved oxygen (DO), pH, conductivity, and oxidation-reduction potential (ORP). Sondes will be calibrated at the beginning of each work day. Calibration will be performed using calibration solutions and procedures prescribed by the manufacturer instructions. The general method of calibration for each sensor is described below.

- DO: two-point calibration including zero and 100% saturation (in air)
- Conductivity: single-point calibration
- Temperature: factory-calibrated (temperatures of all calibration standards should be recorded during calibration)
- pH: two-point calibration including pH values of 4.0, 7.0, or 10.0.
- ORP: single-point calibration
- Turbidity: two-point calibration including standards 0 NTU, 10.0 NTU, 12.7 NTU, 100.0 NTU, 126.0 NTU, 800.0 NTU or 1000.0 NTU

The sonde will be recalibrated as necessary (e.g., when calibration checks indicate incorrect operation) to ensure accurate measurements, and all checks and recalibrations will be recorded on the applicable field forms (e.g. field calibration form). Calibration will also be checked if any readings during sampling are suspect.

2.1.2 End-of-Day Check

At the end of each day, the sondes used for manual sampling should be checked against known standards to confirm that probes are reading correctly. This is done by submerging the probe in the calibration solution used at the beginning of the day and recording the readings, following equipment decontamination per SOP 103. If the reading is not within the accuracy limits of the probe compared to the calibration value, the information should be recorded in the log book and on the Field Log for the locations visited that day.

2.1.3 Decontamination

The sonde will be decontaminated between each sampling location. Decontamination shall be performed according to SOP 103. Personnel and PPE decontamination shall be performed in accordance with the HASP.

2.2 Calibration of the PID/FID

PIDs/FIDs are to be calibrated at the beginning of each sample day and checked for accuracy at the end of each sample day.

2.2.1 Daily Calibration

A PID/FID equipped with a 10.6 eV lamp shall be used to screen sediment samples for VOC impacts. PID/FIDs will be calibrated in a clean environment at the beginning of each workday using a two point field calibration for zero and span gas. The zero calibration, which is made with fresh air, is followed by a second calibration using a 100 ppm isobutylene gas cylinder. Readings will be recorded and should closely match the respective span gas value. Calibration will adhere to procedures prescribed by the manufacturer instructions.

The PID/FID will be recalibrated as necessary (e.g., when calibration checks indicate incorrect operation) to ensure accurate measurements, and all checks and recalibrations will be recorded on the applicable field forms (e.g. field calibration form). Calibration will also be checked if any readings during sampling are suspect. The battery should be charged overnight.

2.2.2 End-of-Day Check

At the end of each sampling day, the PID/FID will be checked for accuracy by analyzing fresh air and 100 ppm isobutylene. The readings should be recorded and fall within the accuracy limits of the probe compared to the calibration value. If the readings are outside of the accuracy limits, then it should be noted in the log book and on the Field Log for the locations visited that day.

Standard Operating Procedure for Groundwater Sampling with PushAhead™ Tool

This standard operating procedure (SOP) describes the process for advancing a soil boring and collecting ground water samples using a PushAhead™ sampler during sonic drilling in unconsolidated material.

- Move the sonic drill with 2-man crew to the boring site. We understand that utilities will be marked and located by others and that hand clearing of the boring location will be necessary. We will establish an exclusion zone.

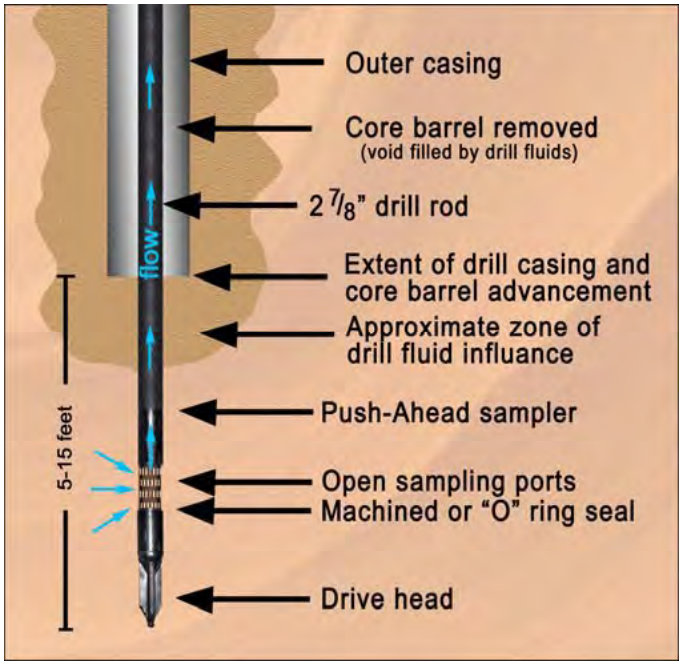
- Set up and prepare to drill, slipping a sheet of plastic under the drill and pulling it up around the tires to act as a containment barrier. It is understood that locations will be chosen to avoid overhead and buried utilities. We will hand clear to 5 feet.

- Using the 4-inch core barrel and 6-inch override casing, we will core through the Coastal Plain sediments to the target depth.

- Drilling will continue making 10-foot-long core runs.

- At the end of any core run we can stop and collect a ground water sample. A decontaminated and sealed PushAhead™ sampler point attached to drilling rods will be inserted through the drill casing and driven beyond the end of the casing to the selected sampling interval, typically 5 to 15 feet beyond the casing, into undisturbed material (see figure).

- An electronic water level indicator will be lowered to the bottom of the sampler to confirm that it is dry and no water has entered during the emplacement of the PushAhead™ sampler.



- The drill rod will be rotated to the right to open the tool to the formation. Ground water will flow into the barrel of the tool and we will monitor the rise with an electronic water level indicator. When there is sufficient water in the sampler, a bailer can be used to collect the sample. We allow 1.5 hours for every sample.

- After each ground water sample is collected, retract the PushAhead™ sampler and drill rods, and continue sonic drilling to the next selected sampling interval (estimated to be 20 feet). Repeat until the desired depth is reached.

- Once we collect the last ground water sample and the PushAhead™ sampler and drill rods have been removed, the borehole will be pressure grouted back to the ground surface. The vibration that we apply to the casing as we pull it will serve to densify and degas the grout as well as to knit the grout into the borehole wall. This will make a superior seal.

Many of the usual benefits of sonic drilling will come into effect during this project:

- Continuous Cores – Continuous sonic cores of soil and aquifer matrix will be provided. You will see everything we penetrate. Cores, instead of dust, mud and chips will help you evaluate the geology.

- Waste Minimization – The core itself should be the only solid IDW. There will be an equal volume of water displaced during grouting. We will not produce a sloppy mess of cuttings and large volumes of water like a conventional rotary process.

- Confidence – We know from past experience in the Coastal Plain formations of southern New Jersey that the sonic drill will be able to core and case to the desired target depth. You will have straight, vertical borings, without offsets due to subsurface obstructions. IDW will be greatly reduced compared to auger or mud rotary drilling methods.

Guidance Manual for Forensic Analysis of Perchlorate in Groundwater using Chlorine and Oxygen Isotopic Analyses

ESTCP Project ER-200509

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14. ABSTRACT
Perchlorate in the environment is derived from both synthetic and natural sources. Synthetic perchlorate salts have been widely used as oxidants by the military and aerospace industry. A variety of commercial products also contain synthetic perchlorate. In addition to synthetic sources, natural perchlorate from both Chilean fertilizers and indigenous sources represents a potentially large source of perchlorate in groundwater and drinking water in the U.S. The key objective of the isotopic techniques described in this guidance manual is to provide evidence concerning the origin of perchlorate in soils and groundwater, and more specifically whether that perchlorate is synthetic or natural. Chlorine and oxygen isotopic analyses of perchlorate provide the primary direct approach whereby different sources of perchlorate can be distinguished from each other. Other isotopic, chemical, and geochemical techniques that can be applied in conjunction with isotopic analyses of perchlorate to provide supporting data in forensic studies are also described.

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perchlorate, stable isotopic analysis, isotope-ratio mass spectrometry, chlorine-37, chlorine-36, oxygen-17, oxygen-18, forensics, groundwater

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Table of Contents

List of Figures ..... **iv**
List of Tables ..... **vi**
List of Appendices ..... **vi**
Acronyms and Abbreviations ..... **vii**
Acknowledgements ..... **xi**
Executive Summary ..... **xii**
1.0 Introduction **1**
1.1 Perchlorate Sources 1
1.1.1 Synthetic Perchlorate 1
1.1.2 Chilean Nitrate Deposits and Fertilizer 2
1.1.3 Indigenous Natural Perchlorate in the U.S. 3
1.1.4 USEPA Guidance on Perchlorate Occurrence 4
1.2 Perchlorate Source Identification 6
1.3 Stable Isotopic Analyses 7
1.4 Isotopes of Chlorine and Oxygen in Perchlorate 9
2.0 Methods of Sampling and Analysis **12**
2.1 Basic Procedures 12
2.2 Sampling Using Ion Exchange (IX) Columns 12
2.2.1 Sampling Column Construction 13
2.2.2 Collection of Perchlorate Samples from Groundwater 15
2.2.3 Sample Replication and Split Samples 18
2.2.4 Sample Preservation and Shipment 22
2.2.5 Column Identification and Chain-of-Custody (COC) 22
2.2.6 Relevant Blanks for Perchlorate Sampling 23
2.2.7 Summary of QA/QC Procedures for Groundwater Sampling 25
2.2.8 Soil Sampling Procedures 26
2.3 Extraction and Purification of Perchlorate on IX Columns 28
2.3.1 Overview of Procedures 28
2.3.2 Resin Removal from IX Columns and Resin Pre-Wash 28
2.3.3 Perchlorate Elution and Analysis 30
2.3.4 Effluent Clean-up and Concentration of Perchlorate 32
2.3.4.1 Iron Removal using Neutralization and Precipitation *32*
2.3.4.2 Iron Removal using Ion Exchange *33*

2.3.5 Perchlorate Crystallization and Recovery 34
2.3.6 Assessing Purity of Recovered Perchlorate Crystals 35
2.3.6.1 Raman Spectroscopy 36
2.3.6.2 Ion Chromatography 39
2.3.7 Reprocessing Impure Samples 41
2.3.8 QA/QC Considerations for Perchlorate Elution and Purification 41
2.4 Analysis of Oxygen Isotopes in Perchlorate by IRMS 43
2.4.1 Terminology and Standards for Oxygen Stable Isotopic Analysis 44
2.4.2 Analysis of δ^{18}O and δ^{17}O by Off-Line Conversion to O_2, with Dual-Inlet Isotope-Ratio Mass Spectrometry (O2-DI-IRMS) 46
2.4.3 Analysis of δ^{18}O by On-Line Conversion to CO, with Continuous-Flow Isotope-Ratio Mass Spectrometry (CO-CF-IRMS) 48
2.5 Analysis of Chlorine Isotopes in Perchlorate by Isotope-Ratio Mass Spectrometry 49
2.5.1 Terminology and Standards for Chlorine Stable Isotopic Analysis 49
2.5.2 Analysis of δ^{37}Cl by Off-Line Conversion to Methyl Chloride, with Dual-Inlet Isotope-Ratio Mass Spectrometry (CH_3Cl-DI-IRMS) 50
2.5.3 Analysis of δ^{37}Cl by On-Line Separation of Methyl Chloride, with Continuous-Flow Isotope-Ratio Mass Spectrometry (CH_3Cl-CF-IRMS) 52
2.6 Analysis of ^{36}Cl from Perchlorate 54
2.7 Summary of Sampling, Purification and Analysis of Chlorine and Oxygen Isotopes in Perchlorate 55
2.8 Supporting Information for Perchlorate Forensic Studies 58
2.8.1 Field Parameters 58
2.8.2 Groundwater-Age Dating 58
2.8.3 Stable Hydrogen and Oxygen Isotopes in Water 59
2.8.4 Stable Nitrogen and Oxygen Isotopes in Nitrate 59
2.8.5 Stable Sulfur and Oxygen Isotopes in Sulfate 59
2.8.6 Dissolved Gas Concentrations 60
2.8.7 Trace Element Concentrations 60
2.8.8 Anion Concentrations 60
3.0 Results and Interpretations 62
3.1 Stable Isotopes of Chlorine and Oxygen in Synthetic Perchlorate 62
3.2 Stable Isotopes of Chlorine and Oxygen in Natural Perchlorate 66
3.2.1 Chilean Nitrate Deposits and Imported Fertilizer 66
3.2.2 Indigenous Sources in the Southwestern U.S. 67

3.3 Abundance of ^{36}Cl in Synthetic and Natural Perchlorate 71
3.3 Abundance of ^{36}Cl in Synthetic and Natural Perchlorate 71
3.4 Post Depositional Modification of Chlorine and Oxygen Isotopes in Perchlorate 73
3.4.1 Isotopic Fractionation of Chorine and Oxygen during Perchlorate Biodegradation 73
3.4.2 Exchange of Oxygen between Perchlorate and Water..... 80
4.0 Case Study of Perchlorate Source Identification: Long Island, New York..... 82
4.1 Characteristics of Sites and Wells..... 83
4.2 Sample Collection and Analyses 86
4.3 Results of Chlorine and Oxygen Isotopic Analyses of Perchlorate..... 86
4.4 Groundwater-Age Dating and Other Supporting Data 89
4.5 Summary of Long Island Perchlorate Source Study..... 90
5.0 Summary and Conclusions 93
6.0 Points of Contact..... 97
7.0 References..... 98

LIST OF FIGURES

Figure 1.1. Perchlorate manufacturers and users (top panel) and releases (bottom panel) as of April 2003.

Figure 2.1. Schematic diagram of ion exchange (IX) column used to collect ClO_4^- from groundwater.

Figure 2.2. Photograph of (A) IX column used to collect ClO_4^- from groundwater and (B) column attached to well during sample collection.

Figure 2.3. Typical set-up of ClO_4^- sampling equipment at a groundwater well.

Figure 2.4. Extraction of ClO_4^- from vadose-zone sediment in West Texas.

Figure 2.5. Elution profiles of SO_4^{2-}, NO_3^-, and ClO_4^- from IX columns using 4 M HCl as an extractant.

Figure 2.6. Elution of ClO_4^- from IX resin using $FeCl_4^-$ solution.

Figure 2.7. Raman spectrum of $CsClO_4$.

Figure 2.8. Raman spectra of $CsClO_4$ contaminated with ~ 0.3 % NO_3^-, 1 % SO_4^{2-}, or 1 % ReO_4^- (by mass) compared to pure $CsClO_4$.

Figure 2.9. Typical ion chromatogram from EPA Method 300.0 for various anions at concentrations of approximately 0.2 mg/L in an aqueous sample.

Figure 2.10. Overview of the procedures involved in the collection, purification, and analysis of ClO_4^- samples for Cl and O isotopic composition.

Figure 3.1. Values of δ^{37}Cl versus δ^{18}O for samples of synthetic ClO_4^- from different sources.

Figure 3.2. Values of δ^{37}Cl versus δ^{18}O for samples of synthetic ClO_4^- from two different manufacturers.

Figure 3.3. Values of Δ^{17}O versus δ^{18}O in Chilean and synthetic ClO_4^-.

Figure 3.4. Comparison of δ^{37}Cl versus δ^{18}O (Plot A) and Δ^{17}O versus δ^{18}O (Plot B) in natural indigenous ClO_4^- in the U.S., natural Chilean ClO_4^-, and synthetic ClO_4^-.

Figure 3.5. Values of $^{36}Cl/Cl$ (mole fraction) versus $\delta^{37}Cl$ in representative samples of synthetic ClO_4^- reagents and products, natural ClO_4^- extracted from soil and groundwater from the Atacama Desert, Chile, and natural ClO_4^- extracted from groundwater and soil from the southwestern U.S.

Figure 3.6. Relation between $\varepsilon^{18}O$ and $\varepsilon^{37}Cl$ during bacterial reduction of ClO_4^-.

Figure 3.7. Relation between $\delta^{18}O$ and $\delta^{37}Cl$ values of synthetic and Chilean ClO_4^-, isotopic compositions of mixtures of these sources, and the isotopic compositions of residual ClO_4^- during biodegradation.

Figure 3.8. Microbial isotopic fractionation trajectory compared to $\delta^{18}O$ and $\delta^{37}Cl$ values of various ClO_4^- sources.

Figure 3.9. Values of $\delta^{18}O$ in ClO_4^- during long-term incubation in ^{18}O-enriched H_2O.

Figure 4.1. Location map of groundwater wells sampled for ClO_4^- source identification on Long Island, New York.

Figure 4.2. Sample collection setup for $ClO_4^-$from a public supply well on Long Island, New York.

Figure 4.3. Comparison of $\delta^{37}Cl$ versus $\delta^{18}O$ (Plot A) and $\Delta^{17}O$ versus $\delta^{18}O$ (Plot B) in $ClO_4^-$from wells on Long Island with those of synthetic and Chilean source materials.

Figure 4.4. Vertical distribution of NO_3-N and ClO_4^- concentrations in nested wells along a transect in the North Fork area of Long Island.

Figure 4.5. National trends of Chilean fertilizer use (Atacama NO_3^-) and total N fertilizer use in the U.S.

LIST OF TABLES

Table 2.1. Examples of Supporting Analytical Methods and Sampling Requirements.

LIST OF APPENDICES

Appendix A: Stable Isotope Data for Perchlorate Sources.

Appendix B: Occurrence and Potential Sources of Perchlorate Releases to the Environment as of April 2003.

ACRONYMS AND ABBREVIATIONS

‰	per mil
δ, Δ	delta, relative difference of isotope ratios
Ag	silver
AgCl	silver chloride
$AgNO_3$	silver nitrate
Al	aluminum
AMS	accelerator mass spectrometry
Ar	argon
Ba	barium
$BaCl_2$	barium chloride
$BaSO_4$	barium sulfate
BOMARC	Boeing and Michigan Aerospace Research Center
Br^-	bromide
BV	bed volumes
°C	degrees Celsius
Ca	calcium
CFC	chlorofluorocarbon
CF-IRMS	continuous-flow isotope ratio mass spectrometry
CH_4	methane
CH_3Cl	methyl chloride
CH_3I	methyl iodide
Cl^-	chloride
Cl	chlorine
^{35}Cl	chlorine-35
^{36}Cl	chlorine-36
^{37}Cl	chlorine-37
ClO_3^-	chlorate
ClO_4^-	perchlorate
cm	centimeters
CO	carbon monoxide
CO_2	carbon dioxide
COC	chain of custody
CsCl	cesium chloride
$CsClO_4$	cesium perchlorate
CsOH	cesium hydroxide
CSIA	compound-specific stable isotope analysis
Cu	copper
DDI	distilled deionized water
DI	deionized water
DI-IRMS	dual-inlet isotope ratio mass spectrometry
DO	dissolved oxygen
DoD	Department of Defense
DTSC	California Department of Toxic Substance Control
EPA	Environmental Protection Agency

ESTCP	Environmental Security Technology Certification Program
Fe^{3+}	Iron (III)
$FeCl_3$	iron (III) chloride
$FeCl_4^-$	tetrachloroferrate
$Fe(OH)_3$	iron (III) hydroxide
g	gram
gal	gallon
GC	gas chromatograph
^3H	tritium
ha	hectare
HCl	hydrochloric acid
$HClO_4$	perchloric acid
HCO_3	bicarbonate
HDPE	high density polyethylene
He	helium
HNO_3	nitric acid
H_2O	water
H_2O_2	hydrogen peroxide
HPLC-UV	high performance liquid chromatography with ultraviolet detection
hr	hours
IAEA	International Atomic Energy Agency
IC	ion chromatography
ICP-MS	inductively coupled plasma mass spectrometry
ID	inner diameter
IO_3^-	iodate
IRMS	isotope-ratio mass-spectrometry
ITRC	Interstate Technology & Regulatory Council
IX	ion exchange
k	one thousand
K	potassium
KCl	potassium chloride
$KClO_4$	potassium perchlorate
kg	kilogram
km^2	square kilometer
KNO_3	potassium nitrate
KOH	potassium hydroxide
L	liter
LC-MS/MS	liquid chromatography-tandem mass spectrometry
µg	microgram
µg/L	microgram per liter
µm	micron
µmol	micromole
M	molar
m	meter
MΩ	megohm
MADEP	Massachusetts Department of Environmental Protection

MCL	maximum contaminant level
MDL	method detection limit
Mg	magnesium
mg	milligram
min	minute
mL	milliliter
mm	millimeter
mM	millimolar
MTBE	methyl *tert*-butyl ether
m/z	mass to charge ratio
n	amount of substance
N	nitrogen or normal or number of entities
N_2	nitrogen gas
Na	sodium
NaCl	sodium chloride
$NaClO_4$	sodium perchlorate
NADP	National Atmospheric Deposition Program
NaOCl	sodium hypochlorite (bleach)
NaOH	sodium hydroxide
NASA	National Aeronautics and Space Administration
Ne	neon
ng	nanogram
NH_4ClO_4	ammonium perchlorate
NIST	National Institute of Standards and Technology
N_2O	nitrous oxide
NO_2^-	nitrite
NO_3^-	nitrate
NO_3-N	nitrate as nitrogen
NPT	National pipe thread
O	oxygen
^{16}O	oxygen-16
^{17}O	oxygen-17
^{18}O	oxygen-18
O_2	oxygen gas
O_3	ozone
OD	outer diameter
ORNL	Oak Ridge National Laboratory
ORP	oxidation-reduction potential
per mil (‰)	part per thousand ($\times 10^{-3}$)
ppb	part per billion ($\times 10^{-9}$)
ppm	part per million ($\times 10^{-6)}$
PO_4^{2-}	phosphate
PRIME	Purdue Rare Isotope Measurement Laboratory
PVC	polyvinyl chloride
QA/QC	Quality Assurance/Quality Control
RbCl	rubidium chloride

$RbClO_4$	rubidium perchlorate
Re	rhenium
ReO_4^-	perrhenate
S	sulfur
Sb	antimony
SCWA	Suffolk County Water Authority
SERDP	Strategic Environmental Research and Development Program
SF_6	sulfur hexafluoride
SHP	Southern High Plains
SLAP	Standard Light Antarctic Precipitation
SMOC	Standard Mean Ocean Chloride
SO_2	sulfur dioxide
SO_4^{2-}	sulfate
Sr	strontium
TcO_4^-	pertechnetate
TOC	total organic carbon
UIC	University of Illinois at Chicago
U.S.	United States
USEPA	United States Environmental Protection Agency
USGS	U.S. Geological Survey
VOCs	volatile organic compounds
VSMOW	Vienna Standard Mean Ocean Water
x	mole fraction
yr	year

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EXECUTIVE SUMMARY

Perchlorate (ClO_4^-) in the environment is derived from both synthetic and natural sources. Synthetic ClO_4^- salts, including ammonium perchlorate (NH_4ClO_4) and potassium perchlorate ($KClO_4$), have been widely used as oxidants by the military and aerospace industry. A variety of commercial products also contain synthetic ClO_4^- including fireworks, matches, air bags, chlorine bleach, safety flares, perchloric acid, and chlorate herbicides. Historical disposal practices by the military, aerospace industry, and chemical manufacturers have resulted in groundwater and drinking water contamination with ClO_4^- in the U.S. Isolated contamination from fireworks, road flares, explosives, and perchloric acid has also been reported. However, ClO_4^- is also a naturally-occurring anion. It is present with sodium nitrate ($NaNO_3$) in surficial deposits in the Atacama Desert of Chile at an average concentration of around 0.1 % (by mass) of the total soluble salt, and these deposits (sometimes referred to as "Chilean caliche") were widely used in the U.S. during the first half of the 20th century as a source of inorganic nitrogen fertilizer. Natural ClO_4^- that is not associated with Chilean fertilizers has also recently been detected in the vadose zone, groundwaters, and mineral deposits collected from the arid southwestern U.S., including 155,000 km^2 of groundwater in the Southern High Plains (SHP) of Texas and New Mexico. In addition to synthetic sources, natural ClO_4^- from both Chilean fertilizers and indigenous sources represents a potentially large source of ClO_4^- in groundwater and drinking water in the U.S.

Increased health concerns about ClO_4^- during the past decade and subsequent regulatory considerations have generated appreciable interest in source identification. The key objective of the isotopic techniques described in this guidance manual is to provide evidence concerning the origin of ClO_4^- in soils and groundwater, and more specifically whether that ClO_4^- is synthetic or natural. Chlorine and oxygen isotopic analyses of ClO_4^- provide the primary direct approach whereby different sources of ClO_4^- can be distinguished from each other. These techniques measure the relative abundances of the stable isotopes of chlorine (^{37}Cl and ^{35}Cl) and oxygen (^{18}O, ^{17}O, and ^{16}O) in ClO_4^- using isotope-ratio mass spectrometry (IRMS). In addition, the relative abundance of the

radioactive chlorine isotope ^{36}Cl is measured using accelerator mass spectrometry (AMS). Taken together, these measurements provide four independent quantities that can be used to distinguish natural and synthetic ClO_4^- sources, to discriminate different types of natural ClO_4^-, and to detect ClO_4^- biodegradation in the environment. Other isotopic, chemical, and geochemical techniques that can be applied in conjunction with isotopic analyses of ClO_4^- to provide supporting data in forensic studies are also described.

This guidance manual is intended to provide details of the methodology used to (1) collect ClO_4^- samples from the environment, particularly from groundwater, which is the main medium of interest for ClO_4^- source identification; (2) purify the collected ClO_4^- samples; (3) conduct O and Cl isotopic analyses on the purified samples; and (4) determine probable sources using the resulting isotope data. Current practices for groundwater sampling and quality assurance for sample collection, purification, and measurement of Cl and O isotopes in ClO_4^- are provided. A detailed case study of source evaluation in groundwater on Long Island is given along with the current literature on the subject of ClO_4^- source discrimination.

1.0 INTRODUCTION

1.1 Perchlorate Sources

The key objective of the isotopic techniques described herein is to provide evidence concerning the origin of perchlorate (ClO_4^-) in groundwater, and more specifically whether that ClO_4^- is synthetic or natural. The following sections summarize current information about the sources of synthetic and natural ClO_4^- in the environment and the potential extent of their distribution. Relevant literature is cited to provide sources of additional information about ClO_4^-.

1.1.1 Synthetic Perchlorate

Ammonium perchlorate (NH_4ClO_4) has been used for several decades in the United States (U.S.) as the primary oxidant in a variety of solid rocket propellants and explosives produced for military and aerospace applications. More than 100 varieties of military rocket motors, as well as the solid rocket boosters for the National Aeronautics and Space Administration (NASA) Space Shuttles, contain NH_4ClO_4 (Cunniff et al., 2006). Potassium perchlorate ($KClO_4$) is also used for many military applications, including U.S. Navy underwater munitions. Besides military propellants and explosives, a variety of commercial products contain synthetic ClO_4^- either intentionally or as a manufacturing byproduct, including fireworks, matches, air bags, chlorine bleach, safety flares, perchloric acid, and chlorate herbicides (Aziz et al., 2006, 2008; Trumpholt et al., 2005). Based on United States Environmental Protection Agency (USEPA) estimates, approximately 4×10^8 kg (400,000 metric tons) of synthetic ClO_4^- has been produced in the U.S. since the 1950's, with an average production rate of 7.1×10^6 kg/yr from 1951-1997 (Dasgupta et al., 2006). Historical testing and disposal practices at some military installations, ClO_4^- production facilities, and aerospace sites have resulted in substantial contamination of soils and groundwater at these locations (Figure 1.1 and Appendix B). Many groundwater ClO_4^- plumes, which are often aerially extensive and have concentrations up to several hundred milligrams per liter of ClO_4^-, have been identified and are subject to site assessment and(or) remediation (e.g., Hatzinger, 2005; ITRC, 2008). However, the contribution of other commercial products as non-point or small point sources of synthetic ClO_4^- is much more difficult to assess and quantify, although road flares, blasting agents, and fireworks have

been indicated as sources of ClO_4^- in some groundwaters (e.g., Böhlke et al., 2009; MADEP, 2007; Munster and Hanson, 2009). Further information on synthetic ClO_4^- sources can be found in previously published reviews (Trumpholt et al., 2005; ITRC, 2008; Aziz et al., 2006).

1.1.2 Chilean Nitrate Deposits and Fertilizer

Natural ClO_4^- has long been known to co-occur with sodium nitrate ($NaNO_3$) in surficial deposits in the Atacama Desert of Chile at an average concentration of around 0.1 % (by mass) of the total soluble salt, but with concentrations as high as 6.8 % reported (Schilt, 1979; Ericksen, 1981, 1983; Dasgupta et al., 2005). The nitrate deposits, sometimes referred to as "Chilean caliche", were widely used in the U.S. during the first half of the 20th century as a source of inorganic nitrogen fertilizer. According to the California Department of Agriculture, more than 477,000 metric tons of Chilean nitrate were used in California as fertilizer between 1923 and 1998 (California Department of Food and Agriculture, 1999). Although man-made nitrogen sources are now used in most fertilizer applications, more than 55,000 metric tons of the Chilean nitrate material was shipped to California between 1995 and 2000, primarily for fertilizer application. There appears to be significant variability in the final ClO_4^- concentration of processed Chilean nitrate fertilizer (as well as the ore from which it is derived), but values ranging from approximately 1,500 to 10,000 mg/kg have been reported in historical samples (Urbansky et al, 2001a, 2001b; Eldridge et al., 2000; Dasgupta et al., 2005). Thus, apart from synthetic sources, past application of Chilean nitrate fertilizer clearly represents a potential source of ClO_4^- in groundwater and drinking water in the U.S. Based on a conservative estimate of 2,000 mg ClO_4^-/kg Chilean fertilizer (Dasgupta et al., 2005), one metric ton of processed Chilean fertilizer likely contained > 2.0 kg of ClO_4^-; enough to contaminate more than 300 million liters of groundwater to above the current California maximum contaminant level (MCL) of 6 μg/L. Additional information on Chilean nitrate fertilizers as a source of ClO_4^- can be found in previously published papers (Dasgupta et al., 2005; Ericksen, 1981, 1983; Jackson et al., 2006; Böhlke et al., 2009). It should be noted that some other fertilizer materials, such as kelp, have also been reported to contain ClO_4^-, but the concentrations in these materials, when detected, are generally orders of magnitude lower than those historically

present in Chilean nitrate, and they are considered unlikely to be of overall environmental significance (Dasgupta et al., 2005; Böhlke et al., 2009).

1.1.3 Indigenous Natural Perchlorate in the U.S.

Natural ClO_4^- that is not associated with fertilizers from the Atacama has also recently been detected in soils, groundwaters, and mineral deposits collected from the arid southwestern U.S., including groundwater underlying an area of 155,000 km^2 in the Southern High Plains (SHP) of Texas and New Mexico (Rajagopolan, 2006; Jackson et al., 2004, 2005, 2006). Based on groundwater age dating, some New Mexico samples (with ClO_4^- concentrations ranging from ~ 0.12 to 1.8 μg/L) were recharged many thousands of years before present, indicating pre-anthropogenic (natural) ClO_4^- sources and accumulation processes (Plummer et al, 2006). This "indigenous" natural ClO_4^- is hypothesized to form initially in the stratosphere through photochemical reactions (Murphy and Thomson, 2000; Dasgupta et al., 2005; Bao and Gu, 2004; Sturchio et al., 2009) and subsequently to deposit at the Earth's surface via precipitation or dry deposition. This hypothesis was supported by a recent study reporting the existence of natural ClO_4^- in precipitation from National Atmospheric Deposition Program (NADP) collectors at 26 sites across the contiguous U.S., Puerto Rico, and Alaska over a 3-yr period at concentrations ranging from <5 ng/L to 102 ng/L (n=1578) (Rajagopalan et al., 2009). In arid regions, such as parts of the southwestern U.S., ClO_4^- in rainwater and dry deposition is expected to accumulate with time in the vadose zone, along with other deposited salts. This hypothesis was confirmed by Rao et al. (2007), who detected ClO_4^- in the vadose zone at several sites in the southwest with an average accumulated mass per unit area of 408±88 g/ha. The ClO_4^- concentrations were correlated (r=0.59-0.99) to meteoric Cl^- accumulated over the last 6 to 100 kyr, indicating that these anions were deposited together via similar processes. Natural indigenous ClO_4^- has also recently been observed to be associated with natural NO_3^- deposits in Death Valley, California at concentrations ranging from 0.25 to 1.7 mg/kg (Jackson et al., 2010).

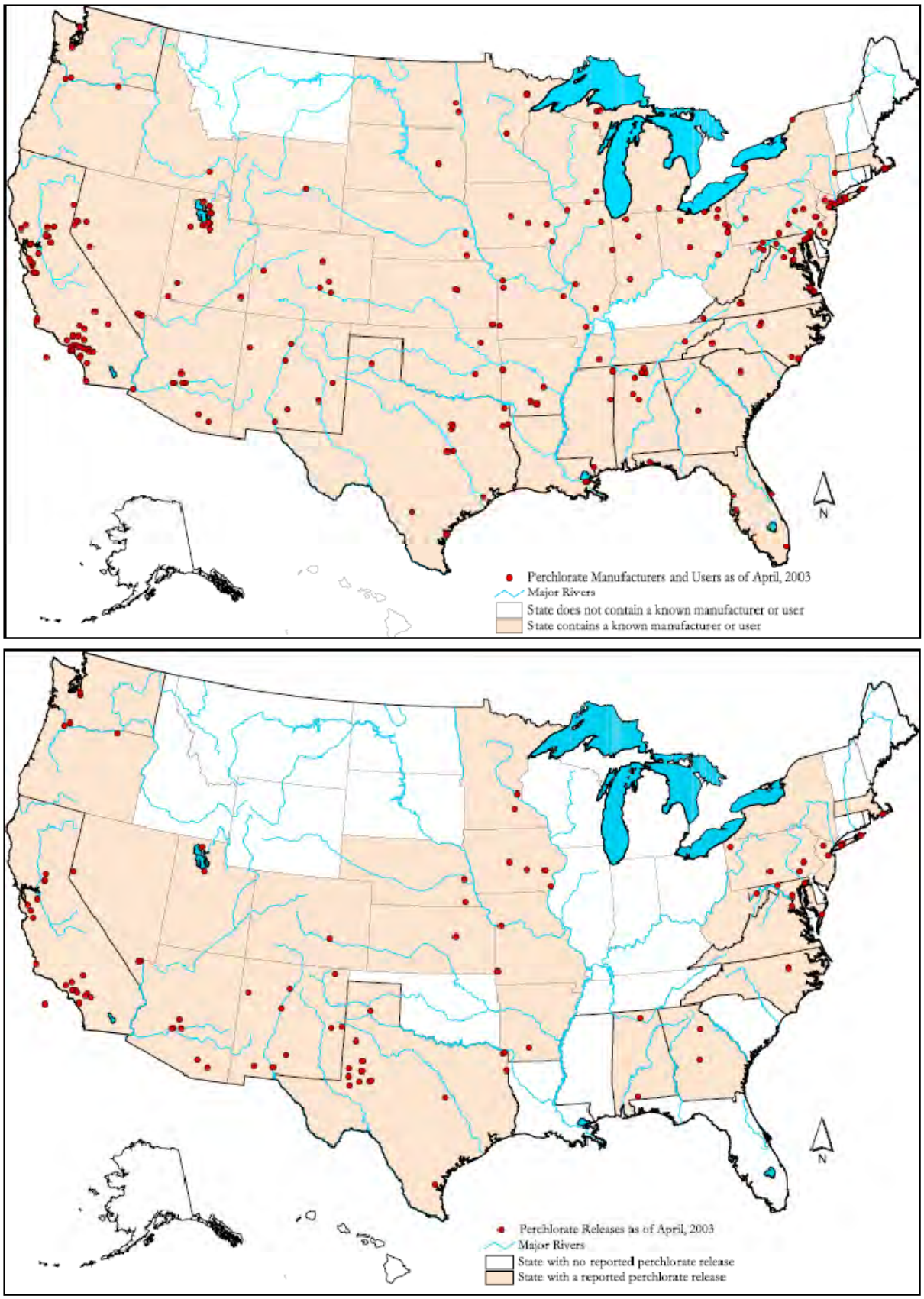
In undisturbed arid regions, atmospheric ClO_4^- is expected to remain primarily in surficial deposits and soils. However, when such environments become subject to large-scale irrigation, such as in the Southern High Plains and other agricultural regions of the western U.S., mobilization of ClO_4^- accumulated in the vadose zone to groundwater is likely. Such

agricultural mobilization is hypothesized to account for the high ClO_4^- concentrations observed in groundwater in West Texas, which has been widely irrigated for several decades for production of cotton and other crops (Rajagopalan et al., 2006). Irrigation is also a likely route of transport to groundwater of ClO_4^- applied to crops with Chilean nitrate fertilizers.

1.1.4 USEPA Guidance on Perchlorate Occurrence

The United States Environmental Protection Agency (USEPA) has been evaluating the occurrence of ClO_4^- for more than a decade and recognizes that the chemical is both widespread in the U.S. and has synthetic and natural origins. Figure 1.1 illustrates the location of various ClO_4^- manufactures and known releases in the U.S., and Appendix B provides more detailed information concerning ClO_4^- manufacturers and users (Mayer, 2003). Additional information on ClO_4^- from the USEPA is available online (http://water.epa.gov/drink/contaminants/unregulated/perchlorate.cfm) and in a recent "Fact Sheet" issued by the agency (USEPA, 2009).

Figure 1.1. Perchlorate manufacturers and users (top panel) and releases as of April 2003. Maps from Mayer (2003).



1.2 Perchlorate Source Identification

With increasing state and federal regulatory pressure to clean up ClO_4^- in groundwater and drinking water to low part-per-billion (ppb; or microgram per liter, μg/L) concentrations, source identification is taking on new importance. Where ClO_4^- is present in groundwater at hundreds to thousands of micrograms per liter, synthetic sources are likely to be the primary source. However, when ClO_4^- concentrations are relatively low (e.g., < 20 μg/L) and a military, commercial or manufacturing source is not readily apparent or is not indicated based on hydrogeological data (e.g., contamination is upgradient of a known military source area), then natural ClO_4^-, either from Chilean fertilizers or natural sources indigenous to the U.S., should be considered as a potential source in addition to non-point synthetic sources such as road flares, blasting agents, and fireworks. This is particularly true in historical agricultural areas that may have been subject to both fertilization and irrigation.

The most common analytical method to quantify ClO_4^- concentrations in water and other matrices, USEPA Method 314.0 (ion chromatography; USEPA, 1999), is incapable of distinguishing natural from synthetic ClO_4^-. Other second-generation methods for ClO_4^- analysis, including USEPA Method 331.0 (ion chromatography with electrospray ionization/mass spectrometry; USEPA, 2005a), USEPA Method 332.0 (high-performance liquid chromatography with electrospray ionization/mass spectrometry; USEPA, 2005b), USEPA Method 6850 (high performance liquid chromatography with electrospray ionization/mass spectrometry, USEPA 2007a), and USEPA Method 6860 (ion chromatography with electrospray ionization/mass spectrometry; USEPA, 2007b), although utilizing mass spectrometry for ClO_4^- detection, also cannot measure relative isotopic abundances with the sensitivity and precision required for forensic analysis. A summary of these and other analytical methods for ClO_4^- is provided in USEPA (2009).

The main approach described in this document, chlorine and oxygen isotopic analysis of ClO_4^-, is the primary direct method whereby different sources of ClO_4^- may be distinguished from each other. This approach yields accurate and precise measurements of the relative abundances of the stable isotopes of chlorine (^{37}Cl and ^{35}Cl) and oxygen (^{18}O,

^{17}O, and ^{16}O) in ClO_4^- using isotope-ratio mass-spectrometry (IRMS) as described further in Sections 2.4 and 2.5. It also can yield the relative abundance of the radioactive chlorine isotope ^{36}Cl using accelerator mass spectrometry (AMS) as described further in Section 2.6. Altogether, these measurements provide four independent quantities (isotope abundance ratios) for distinguishing ClO_4^- sources and potential transformations in the environment.

Other isotopic, chemical, and geochemical techniques that can be applied in conjunction with isotopic analyses of ClO_4^- to provide supporting data are described in Section 2.8. Methods used for Cl and O isotopic analyses of ClO_4^- are presented in the subsequent section to provide background on this general approach, and current isotopic data for ClO_4^- are described in Section 3.0. A case study that illustrates the application of IRMS of Cl and O stable isotopes to distinguish sources of ClO_4^- on Long Island, New York is provided in Section 4.0.

1.3 Stable Isotopic Analyses

Isotopes of a given element have the same number of protons and electrons (thus defining the element), but a different numbers of neutrons, the latter of which provide mass but no charge. Some isotopes are subject to nuclear decay, and are termed radioactive, while others are stable. The methods for isotopic analyses of ClO_4^- described herein refer primarily to the stable isotopes of Cl and O; analysis of ^{36}Cl, a long-lived radioactive isotope of Cl, also is included as another promising forensics tool. Because isotopes of a given element differ in mass, they exhibit slight behavioral differences, such that a variety of physical, chemical, and biological processes can alter the relative abundances of isotopes of elements in a given chemical compound, a process termed “isotopic fractionation”. Isotopic fractionation processes, most of which are mass-dependent (equilibrium and kinetic processes that are based upon mass differences), and some of which are non-mass-dependent (processes that do not occur in proportion to mass differences) commonly cause different samples containing a given element or chemical compound to have distinct isotopic compositions. These different isotope ratios can be indicative of the origin of a molecule, and thus have forensic science applications; for example carbon and chlorine

isotope ratios of chlorinated solvents produced in different facilities can have different isotopic compositions (Beneteau et al., 1999). In addition, the stable isotope ratios of elements in a parent molecule often change systematically during biodegradation and other degradation processes (e.g., Hunkeler et al., 2008); thus, stable isotope methods can provide unique insights into *in situ* transformation processes and natural attenuation of many constituents in the environment. Additional details and reviews of stable isotope terminology and general principles are provided elsewhere (Hunkeler et al., 2008; Sharp, 2007; Clark and Fritz, 1997; Kendall and Caldwell, 1998; Coplen, 2011).

As noted previously, measurements of stable isotopic composition are conducted using an IRMS. This instrument is designed to measure precisely the relative differences in the isotope ratios of a given element between different substances, rather than the actual absolute ratios in any given substance, which are more difficult to determine accurately. Relative stable isotope ratios of elements are generally reported as differences from those of internationally recognized measurement standards, so that measurements from different laboratories can be compared. The relative differences of isotope ratios are reported as "delta" (δ) values (Coplen, 2011). The general expression used to report relative abundances of stable isotopes is provided below in Equation 2.1, with Cl isotopes (^{37}Cl and ^{35}Cl) as an example.

[Eq. 2.1] $\delta^{37}\mathrm{Cl}_{\mathrm{P/Q}} = [R(^{37}\mathrm{Cl}/^{35}\mathrm{Cl})_{\mathrm{P}} - R(^{37}\mathrm{Cl}/^{35}\mathrm{Cl})_{\mathrm{Q}}] / R(^{37}\mathrm{Cl}/^{35}\mathrm{Cl})_{\mathrm{Q}}$

R = ratio of the atomic or molar abundances (N, number of entities; alternatively n, amount of substance) of two isotopes of an element, with the isotope of higher atomic mass normally in the numerator, in this case: $R(^{37}\mathrm{Cl}/^{35}\mathrm{Cl}) = N(^{37}\mathrm{Cl})/N(^{35}\mathrm{Cl}) = n(^{37}\mathrm{Cl})/n(^{35}\mathrm{Cl})$

$R(^{37}\mathrm{Cl}/^{35}\mathrm{Cl})_{\mathrm{P}}$ = number ratio of isotopes in substance P

$R(^{37}\mathrm{Cl}/^{35}\mathrm{Cl})_{\mathrm{Q}}$ = number ratio of isotopes in substance Q

The international measurement standard for δ^{37}Cl is "Standard Mean Ocean Chloride" (SMOC), which takes the place of substance Q in Equation 2.1 for reporting the δ^{37}Cl value of a sample (substance P in Equation 2.1), unless stated otherwise. Because delta values

(e.g., δ^{37}Cl) typically are small, they commonly are reported in parts per thousand (per mil, with symbol ‰). A positive δ value indicates that the ratio of the heavy/light isotopes in the sample is higher than that of the standard, while a negative δ value indicates that the ratio of the heavy/light isotopes in the sample is lower than that of the standard. For example, if δ^{37}Cl is reported as -18 ‰, this means that $R(^{37}Cl/^{35}Cl)$ in the sample is 18 parts-per-thousand or 1.8 percent lower than $R(^{37}Cl/^{35}Cl)$ in the standard (SMOC), for which the δ^{37}Cl value would be 0 by definition. It is important to note that absolute isotope ratios (R) are difficult to measure as precisely as relative differences of isotope ratios (δ), so that most IRMS equipment and techniques are designed to produce high-precision comparisons of the isotope ratios of samples and standards. The value of $R(^{37}Cl/^{35}Cl)$ in seawater has been reported as 0.31940 ± 0.00007 (Xiao et al., 2002) and found to be homogeneous (to within ±0.1 ‰) in samples of seawater from around the world (Godon et al., 2004). In practice, stable isotope laboratories typically have quantities of secondary isotope reference materials that are used routinely. These secondary reference materials are calibrated against internationally recognized reference materials such as those provided by the National Institute of Standards and Technology or the International Atomic Energy Agency. The secondary isotope reference materials must be isotopically homogeneous at the scale of analysis. In addition, it is preferred that isotopic reference materials be similar chemically to the samples being analyzed, and that samples and reference materials are analyzed together using identical procedures, as discussed in sections 2.4 and 2.5 (see also Werner and Brand, 2001). For oxygen stable isotopes, the international measurement standard is Vienna Mean Ocean Water (VSMOW), for which δ^{17}O and δ^{18}O are exactly 0 by definition.

1.4 Isotopes of Chlorine and Oxygen in Perchlorate

Both of the elements comprising the ClO_4^- molecule (i.e., Cl and O) have more than one stable isotope. Oxygen has three stable isotopes (^{16}O, ^{17}O, and ^{18}O), which have molar abundances (mole fractions) of approximately 99.76206 %, 0.03790 %, and 0.20004 %, respectively, in the VSMOW standard (Coplen et al., 2002). Chlorine has two stable isotopes (^{35}Cl and ^{37}Cl), with molar abundances of approximately 75.779 % and 24.221 %, respectively, in the SMOC standard (Coplen et al., 2002). Chlorine also has a long-lived

radioactive isotope (^{36}Cl) with a half-life of ~ 301,000 yr, whose relative abundance is small (typically $<10^{-15}$ to 10^{-12} relative to the stable Cl isotopes) but can be useful for studying origins of Cl-bearing compounds (Phillips, 2000). Techniques to determine relative stable isotope ratios of chlorine (^{37}Cl and ^{35}Cl) in the ClO_4^- molecule were first reported by Ader et al. (2001) and Sturchio et al. (2003). Subsequently, methods for analysis of relative isotope ratios of oxygen (^{18}O, ^{17}O, and ^{16}O) in ClO_4^- were described (Bao and Gu, 2004; Böhlke et al., 2005). Methods to collect and purify ClO_4^- from environmental samples, including groundwater, minerals, and soils have been progressing for several years, as have the relevant IRMS techniques for Cl and O isotopic analyses of ClO_4^-. Recent developments in these methods are summarized in several different papers and book chapters (Gu et al., 2011; Sturchio et al., 2007, 2011; Jackson et al., 2010; Böhlke et al., 2009; Hatzinger et al., 2009). The first analyses of ^{36}Cl in different ClO_4^- samples also was reported recently (Sturchio et al., 2009). The results gained from analyses of O and Cl stable isotopes and ^{36}Cl in ClO_4^- using these new methods provide critical insight into the origins of ClO_4^-, both as an environmental contaminant and a naturally formed anion in the environment. These results are described in Section 3.0.

One objective of this guidance manual is to provide details concerning the methodology used to (1) collect ClO_4^- samples from the environment, particularly from groundwater, which is the main medium of interest for ClO_4^- source identification, (2) purify the collected ClO_4^- samples; (3) conduct O and Cl isotopic analyses on the purified samples; and (4) determine probable sources using the resulting isotope data. These details are provided in Section 2.0 (sample collection, purification, and isotopic analyses) and 3.0 (current isotope data and evaluation of sources). In addition, some types of supporting information that are often useful for evaluating ClO_4^- isotopic data are provided in Section 2.8, and a case study of source evaluation in groundwater on Long Island is given in Section 4.0. It should be noted that, compared to many other environmental sampling and analysis techniques, compound-specific stable isotopic analysis (CSIA) is a relatively specialized technique that continues to evolve, and ClO_4^- stable isotopic analyses have only been performed since 2004. Thus, the techniques and Quality Assurance/Quality Control (QA/QC) parameters are still being refined, and there are no USEPA-certified methods for CSIA of organic or inorganic compounds. However, a recent document from the USEPA,

which acknowledges both the utility of CSIA as well as the newness of this approach, provides "...general recommendations on good practice for sampling groundwater for CSIA, and quality assurance recommendations for measurement of isotope ratios." (Hunkeler et al., 2008). While the USEPA document is focused primarily on (1) carbon isotopic analysis in organic compounds and (2) utilizing CSIA to document biodegradation, some of the general principles apply to Cl and O isotopic analyses of ClO_4^- and are cited herein where appropriate.

This guidance document primarily describes the sampling and analysis methods that have been developed and are now used routinely for measuring Cl and O isotope ratios in ClO_4^-, and it provides initial recommendations for appropriate QA/QC protocols. This document, along with the growing published, peer-reviewed literature on Cl and O isotopic analyses of ClO_4^-, is intended to provide guidance concerning the application of the method and a summary of the data generated by the method to date.

2.0 METHODS OF SAMPLING AND ANALYSIS

2.1 Basic Procedures

This section of the document is designed to provide guidance for the sampling and analysis of ClO_4^- for Cl and O stable isotopes and ^{36}Cl in water samples, including recommendations for QA/QC. Some details are also provided for sample collection and processing from solid media, such as soils. Methods for determining the isotopic composition of ClO_4^- consist of six basic steps:

(1) Sampling using ion exchange (IX) columns
(2) Extraction and purification of ClO_4^- from IX columns
(3) Verification of sample purity
(4) Analysis of stable O isotopes in ClO_4^- by IRMS
(5) Analysis of stable Cl isotopes in ClO_4^- by IRMS
(6) Analysis of ^{36}Cl by AMS

Abbreviated descriptions of the fundamental methods utilized for this procedure have been published in several peer-reviewed papers and book chapters, including Bao and Gu (2004); Sturchio et al. (2006, 2007, 2009, 2011); Böhlke et al. (2005, 2009); Hatzinger et al. (2009); Jackson et al. (2010); and Gu et al. (2011). Because these methods are still evolving as part of ongoing SERDP (ER-1435) and ESTCP (ER-200509) projects, various procedures described herein are likely to undergo modification and refinement with time. However, the method described herein and in the aforementioned literature has thus far proven to be a robust approach to evaluate ClO_4^- sources in groundwater and represents the current state-of-the art at the time of preparation of this document.

2.2 Sampling Using Ion Exchange (IX) Columns

Approximately 20 µmol of pure ClO_4^- salt (as $CsClO_4$ or KClO4, prepared as described in Section 2.3) is normally sufficient to obtain duplicate stable isotope ratio measurements by IRMS for both O and Cl in the ClO_4^- ion. However, because of potential losses during

sample purification (Section 2.3), and allowing sufficient sample for ^{36}Cl and replicate analyses, it is desirable to collect samples containing at least 100 µmol (i.e. 10 mg) of ClO_4^- from each source. The following sections focus on sample collection from a groundwater source, which is the most typical application of this method. Section 2.2.8 provides a brief description of sampling techniques for soils. For groundwaters with low ClO_4^- concentrations (i.e., < 10 µg/L), collecting 10 mg of ClO_4^- can be challenging. For example, if the ClO_4^- concentration in a well is 5 µg/L, then 2000 L (~530 gal) of water is required to obtain the necessary 10 mg. Shipping this volume of water is impractical. Rather, small columns containing about 100 mL (~ 60 g dry wt) of Purolite A-530E ClO_4^--specific anion exchange resin (IX resin) have been developed and deployed routinely for field use. Water is passed through these columns, and the ClO_4^- is trapped by the IX resin. Although many hours may be required for sample collection in some cases (flow rates up to 2 liters per minute (L/min) are recommended), the columns are capable of trapping 10 mg of ClO_4^- on a small volume of resin. Water bodies with ClO_4^- concentrations as low as 0.05 µg/L have been sampled successfully with cumulative pumping times of days to weeks. The ClO_4^- is then extracted from the resin and purified prior to IRMS analyses, as described in Section 2.3.

2.2.1 Sampling Column Construction

The sampling columns used to collect ClO_4^- in the field are custom made. They are simple to construct, and various design modifications are possible based on the specific application. The design and materials for a typical 100-mL sampling column are provided in Figure 2.1. This basic column design has been used in the field for ClO_4^- sample collection at numerous sites (e.g., Böhlke et al., 2005, 2009; Jackson et al., 2010). The column consists of a 1-1/4 inch Schedule 80 polyvinyl chloride (PVC) pipe (Figure, 2.1, Item D). Clear PVC is recommended so that the resin is visible during sampling, and any channeling of groundwater or trapped air can be observed and corrected. To construct the column, a Teflon or stainless steel screen (100 mesh) is initially cut in a circle to a diameter of 1-5/8 inches, which matches the outer diameter (OD) of the clear PVC pipe. The screen is then glued in place on one end of the pipe. A 1-1/4 inch Schedule 40 PVC end cap (Figure 2.1; Item E) is then packed partially with glass wool or glass fiber filters (to fill the void in the

end cap between the screen and the end of the cap) and glued with PVC primer and glue to the column body. The end cap should be drilled in the center (1/4 inch bit) and fitted with a 1/4 x 1/8-inch National Pipe Thread (NPT) polypropylene barbed hose fitting (Item A) prior to column construction. A similar-sized brass fitting may be substituted. A 1/4-inch PVC Schedule 40 male adaptor (socket weld with threaded end) should then be glued with PVC glue to the open end of the clear PVC pipe (Figure 2.1; Item G).

At this point in construction, the column can be filled with Purolite A-530E strong base anion exchange resin (Purolite Co., Bala Cynwyd, Pennsylvania), a bifunctional resin that was originally developed at Oak Ridge National Laboratory, Oak Ridge, Tennessee, for selective adsorption of pertechnetate (TcO_4^-) and was found to be equally effective for ClO_4^- (Gu et al., 2000, 2007; Gu and Brown, 2006). Other resins should not be substituted at present, because the ClO_4^- extraction process is specific to this resin. The resin should be wet with ClO_4^--free deionized water for a few hours prior to packing to allow expansion, and ~ 100 mL of wet resin will fill the column to the top of the male adaptor (Figure 2.1; Item G). The column should be gently tapped to remove any air bubbles. Once the resin is added, the top of the column should be covered with a second Teflon or stainless steel screen (1-5/8 inches in diameter). This screen should not be glued. The open end of the column can then be sealed with a threaded 1-1/4-inch Schedule 80 PVC end cap (Figure 2.1; Item F), which is packed partially with glass wool or glass filter fibers and fitted with a 1/4 x 1/8-inch polypropylene or brass barbed hose fitting as described previously for the influent end of the column (Figure 2.1; Item A). The end cap should be threaded tightly. The assembled column should be flushed briefly with deionized water at a flow rate of 2 to 3 L/min to check for potential leaks under simulated field sampling conditions. A single piece of Tygon tubing (1/4 inch ID by 3/8 inch OD; Fig 2.1, Item B) should then be connected to each of the barb fittings using hose clamps for column storage. It is recommended that the sampling columns are stored at 4 °C to prevent any bacterial or fungal growth in the tubing prior to use.

2.2.2 Collection of Perchlorate Samples from Groundwater

A groundwater well can be sampled for ClO_4^- using either a submersible pump (e.g., Grundfos “Redi-flo" or equivalent) or by sampling a sidestream from a municipal supply well or a household well that already has a submersible or external pump in place. Bladder pumps, bailers, and inertia pumps are generally not suitable for ClO_4^- sampling with IX columns because the pressures and/or volumes are not usually adequate for sample collection. In those instances in which ClO_4^- concentrations in groundwater are relatively high such that bulk water samples can be collected and transported to the laboratory (e.g., a 5-L volume of water from a well with ClO_4^- concentration of 2 mg/L), the aforementioned pumps can be used for groundwater sampling. Typically, however, groundwater with ClO_4^- of unknown origin has concentrations that are far below that necessary to collect bulk water samples.

General procedures for groundwater sampling with a submersible pump are provided in several documents (e.g., Nielsen and Nielsen, 2007; Barcelona et al., 1985), but it should be noted that the details vary by organization (e.g., USGS, USEPA, state environmental agencies), and often by project site. USEPA recommendations for groundwater sampling are provided in Puls and Barcelona (1996) and Yeskis and Zavala (2002) and are summarized for CSIA of organic compounds in Hunkeler et al. (2008). It is recommended that typical procedures for well preparation and/or purging, which also vary among state and federal regulatory organizations, and sometimes by site, are followed prior to sampling. In general, well purging/preparation either entails (1) calculation of the total well casing volume based on well diameter and water depth, and pumping 2 to 3 well volumes at a rapid rate prior to sampling or (2) pumping water at a continuous flow rate and continuously measuring key field parameters such as pH, oxidation-reduction potential, turbidity, and dissolved oxygen with a field meter until they are stable, at which time water samples are collected (Hunkeler et al., 2008; Puls and Barcelona, 1996). Either of these techniques can be used to effectively purge a well prior to collection of ClO_4^- samples for isotopic analysis. However, the flow rates employed using the second approach, which is sometimes called “low-flow” sampling, may need to be increased somewhat compared to typical guidance (i.e., to 2 L/min in some instances). However, as long as field parameters

are stable prior to sampling, the groundwater passed through the column should be representative of that entering the screened interval of the well.

During sampling, water is pumped directly from a well or, in some instances from a tap or faucet, to the inlet port of the column using tubing and metal and/or plastic fittings and connections. Because ClO_4^- has a low affinity for most tubing materials, the tubing selected for sampling is not critical. For submersible pump applications, ¼-inch ID by 3/8-inch OD polyethylene tubing commonly is used. Because well water commonly has some turbidity due to suspended sediments or other precipitates, it is recommended that a cartridge pre-filter be placed in-line before the IX column to prevent fouling of the IX resin and a consequent increase in pressure across the column. For water with low turbidity, a 5.0-μM high capacity cartridge filter can be used as a pre-filter (e.g., Pall Co.; http://labfilters.pall.com/catalog/laboratory_20031.asp). If the water has high turbidity, a large capacity household sediment filter can be placed in-line (e.g., General Electric Co., FXHSC whole house filter). Hose clamps should be used to attach tubing to the IX column, in-line filter, and any other places where the tubing is not continuous (e.g., reducer, etc) and pressure buildup may occur. A typical column setup for a groundwater well is provided in Figure 2.3. For household sampling, a barbed hose fitting and tubing can be used to connect directly between an outside house faucet and the IX column using polyethylene, Tygon, or other tubing. A cartridge pre-filter generally is not required for this application.

Columns should be operated in an upflow direction (vertical orientation) and the flow direction should be marked. For the typical 100-mL column set-up as shown in Figs 2.1-2.3, it is recommended that flow rates do not exceed 2 L/min to allow adequate residence time for ClO_4^- adsorption in the IX resin within the column. Prior to initiating groundwater flow through the column, and periodically thereafter (with intervals determined by expected sampling time), groundwater samples may be collected prior to the IX column (influent) and after the column (effluent) for analysis of ClO_4^- concentration by USEPA Method 314.0 or other certified method. In instances where influent concentrations of ClO_4^- to the columns are low (e.g., < 2 μg/L), more sensitive mass-spectrometric methods

may be required for these analyses (see Section 1.2). For U.S. Department of Defense (DoD) applications, sample collection procedures and certified methods are available (DoD, 2007). If the sampling is expected to take several hours based on the groundwater concentration, which is typical, hourly sampling of influent and effluent is recommended. The flow rate of water through the column should also be recorded when the samples are collected and adjusted if necessary. For shorter sampling events, more frequent influent and effluent samples can be taken (e.g., every 1/2 hr for a 3-hr sample collection). The concentration measurements and flow rates during each sampling event allow a mass balance determination to be conducted for ClO_4^- (i.e., how much ClO_4^- is expected on each IX column). Groundwater should be passed through each column until an estimated mass of 10 mg of ClO_4^- is present on the resin based upon influent concentrations and flow rate. For example, if the influent ClO_4^- concentration is 3 μg/L and the flow rate to the column is 2 L/min, then 360 μg of ClO_4^- is expected to be adsorbed in the resin for each hour of operation. Thus, a total collection time of 28 hr would be recommended for collection of the desired 10 mg of ClO_4^-.

Breakthrough of ClO_4^- from IX columns can occur in groundwater, particularly in groundwater with high NO_3^-/ClO_4^- ratios or elevated DOC concentrations. In most groundwaters, breakthrough of ClO_4^- will be <10 % of the total ClO_4^- concentration in the influent water. However, in instances in which influent NO_3^- concentrations are high (e.g., > 1 mM NO_3^-), higher ClO_4^- breakthrough can occur with time. As part of ESTCP Project ER-200509, experiments have been conducted to determine whether isotopic fractionation of O or Cl in ClO_4^- occurs as a function of the fraction of ClO_4^- breakthrough. These results are not yet published. However, preliminary data indicate that the change in O isotope values is negligible for $\Delta^{17}O$ even if the concentration of ClO_4^- in the column effluent reaches > 90 % of the influent concentration (i.e., < 10 % retention on the column, which is far greater breakthrough than expected or previously observed in a field setting). Slight, but measurable, isotopic fractionation was indicated by $\delta^{18}O$ data when there was an artificially high fraction of ClO_4^- breakthrough. The change in $\delta^{18}O$ in samples with > 90 % breakthrough in effluent compared to influent (which occurred in laboratory columns receiving 2 μM ClO_4^- and 160 mM NO_3-N) was ~ 1 ‰, which, while statistically

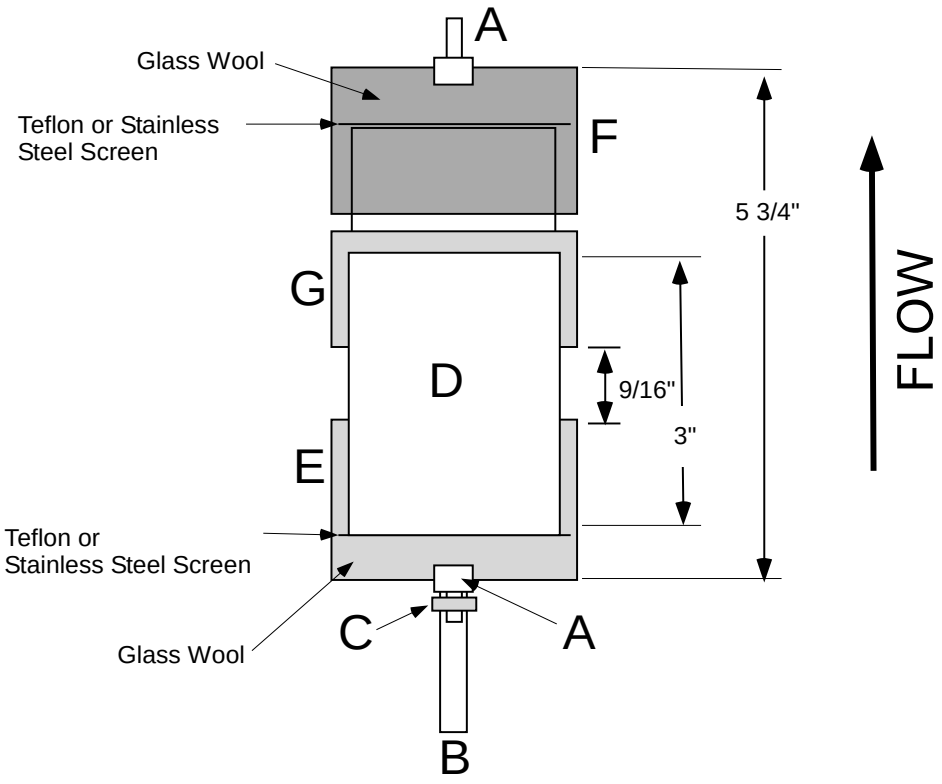
significant, is not large enough to alter conclusions in forensic evaluations based on the current measured values of synthetic ClO_4^-, Chilean nitrate-associated ClO_4^-, or indigenous natural ClO_4^- (See Section 3.0). Preliminary data indicate corresponding changes in $\delta^{37}Cl$ accompanying column breakthrough are smaller than those of $\delta^{18}O$.

2.2.3 Sample Replication and Split Samples

In many instances, single IX columns are collected from each well. However, it is possible to collect replicate samples from a single well during sampling by connecting multiple IX columns to a single submersible pump as shown in Figure 2.3. Most submersible pumps will easily supply the flow needed for duplicate columns if the well yield is adequate. One difficulty with this approach is that flow through the columns may vary with time if different backpressures develop. This may be resolved by connecting an adjustable valve in place to split the flow rather than a simple "Y" splitter in the tubing, as represented in Figure 2.3, and adjusting relative flow to each column with time. If sufficient ClO_4^- is trapped on each column, duplicate samples will be available for extraction and isotopic analysis, thus allowing evaluation of method precision. It is also possible to preserve (with 0.05 N HCl as described in Section 2.2.4) and archive the duplicate column for analysis in the event that the first sample is lost or otherwise compromised during analysis. When wells have very low ClO_4^- concentrations (e.g., < 1 μg/L), duplicate columns are recommended (if feasible based on well yield) to increase the total ClO_4^- collected with time. In this case, the contents of the columns can be combined to a single sample during processing to ensure that enough ClO_4^- is available for analysis.

Split samples are often collected from one or more wells during a field project to compare results between analytical laboratories and verify results from the contracted laboratory (e.g., Nielsen and Nielsen, 2007; Keefe et al., 2003). These samples are either collected close together in time or they are prepared by homogenizing a single sample, and then the replicates are shipped to two different laboratories. Although similar practices would be desirable for determination of Cl and O isotopic composition of ClO_4^-, there is only one laboratory currently that conducts sample preparation and analysis as a commercial service (See Section 5.0); thus, a true sample split currently is not possible. If other commercial laboratories offer these services in the future, split sampling will be possible.

Figure 2.1. Schematic diagram of ion exchange (IX) column used to collect ClO_4^- from groundwater.



A = 1/4" x 1/8" polypropylene or brass hose fitting (2)
B = Tygon tubing (2 ft) 1/4"x3/8"
C = Hose clamp (1)
D = 1 1/4" clear PVC pipe, sch 80 (2 3/4")
E = 1 1/4" PVC sch 40 end cap (1) F = 1 1/4" PVC sch 80 threaded cap (1)
G = 1 1/4" PVC sch 40 male adaptor NPT x socket weld (1)

Figure 2.2. Photograph of (A) IX column used to collect ClO_4^- from groundwater and (b) column attached to well during sample collection.

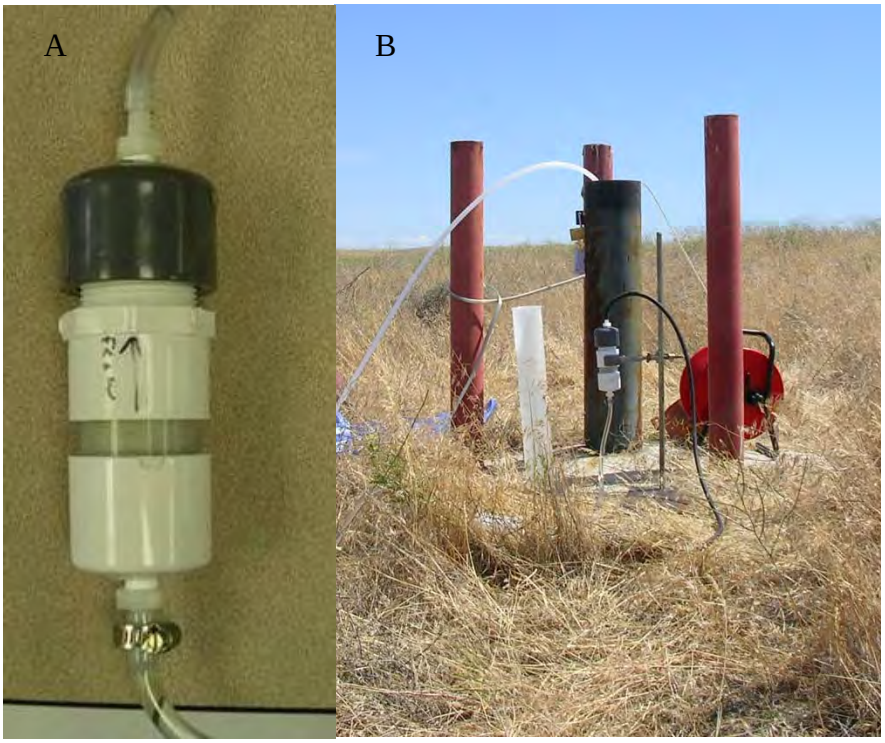
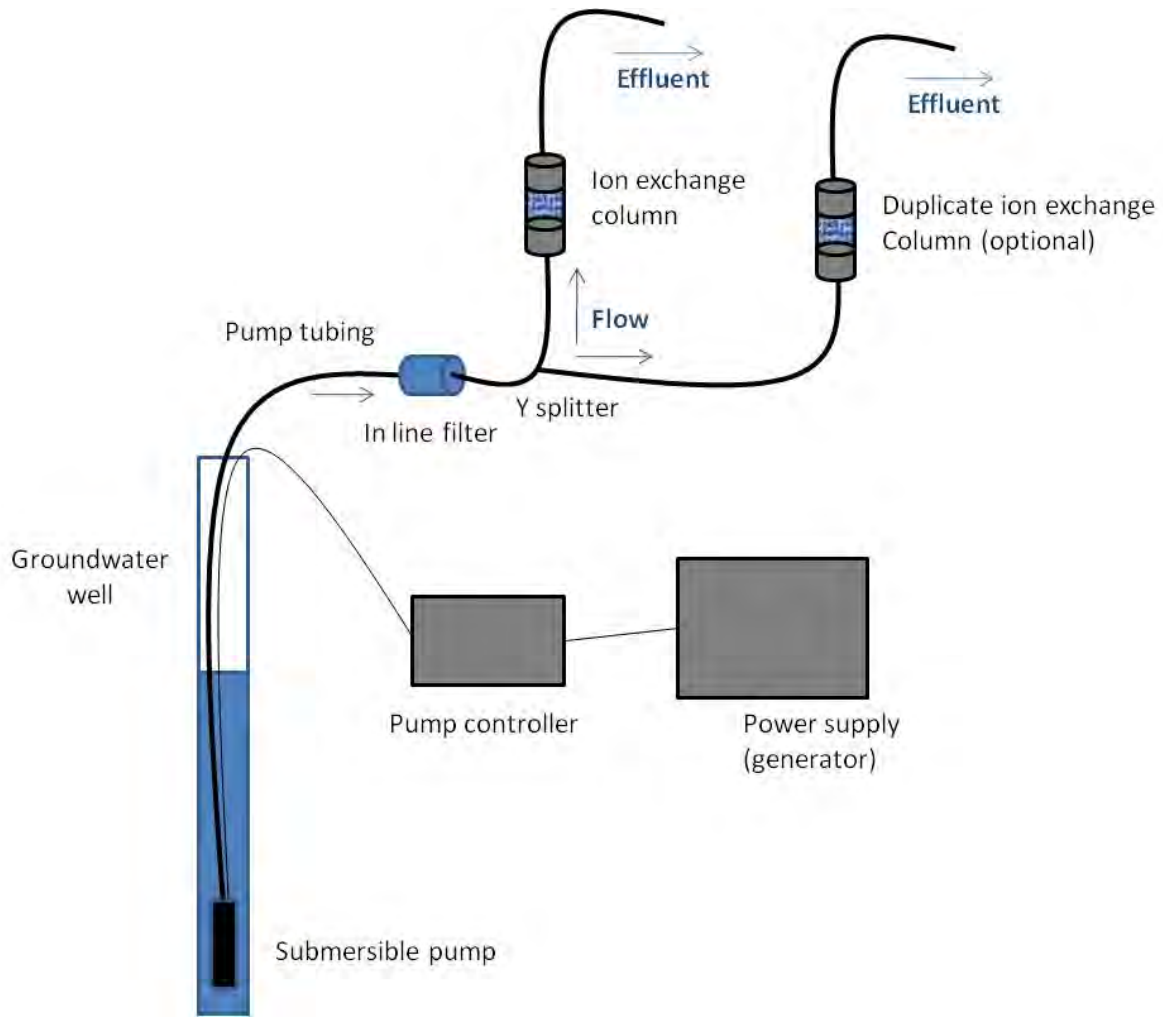


Figure 2.3. Typical set-up of ClO_4^- sampling equipment at a groundwater well. A duplicate column is recommended but optional.



2.2.4 Sample Preservation and Shipment

Once the desired amount of water has been passed through the IX column to collect ClO_4, the column should be disconnected from the pump, drained of standing water, and sealed by attaching a small piece of tubing from one end to the other (i.e., attached to the hose barbs on each end with a hose clamp). Alternatively, hose barbs may be removed and replaced with threaded plugs. The resin should remain moist but not saturated with water. The column should then be placed in double Ziploc style storage bags and stored/shipped at 4 °C for preservation prior to processing. In most instances, ClO_4^- will be stable on the column under these conditions because air is present in the column, and ClO_4^- biodegradation does not occur under aerobic conditions (Coates and Achenbach, 2004). Adsorption of the ClO_4^- onto the resin is also expected to inhibit biodegradation. However, if a sample is collected from anoxic groundwater and(or) water with high total organic carbon content (e.g., lake water, groundwater amended with a substrate to enhance biodegradation, etc), the potential for ClO_4^- biodegradation on the column exists. In these instances, dilute HCl can be used to preserve the column prior to processing. To preserve with HCl, the column should be drained of groundwater, and then the resin should be saturated with a solution of 0.05 N HCl, which will reduce the pH to < 2 (Hatzinger et al., 2009). The ends should then be sealed with a single piece of tubing using hose clamps as described previously, and the column should be placed in double Ziploc style storage bags. The preserved columns should be stored/shipped at 4 °C prior to processing. At present, columns do not have a maximum "hold time" prior to extraction and analysis.

2.2.5 Column Identification and Chain-of-Custody (COC)

Basic chain-of-custody (COC) procedures used for typical groundwater sampling should also be used for ClO_4^- sampling. These procedures vary somewhat by state and/or regulatory organization, and sometimes by site. Appropriate procedures should be reviewed and followed. Prior to groundwater sample collection, each IX column should initially be labeled with a unique identifier (tags or permanent ink marking), as well as the sample well location and ID. This column ID number should also be recorded on a COC form prepared during the sampling event along with the well identification number and location. During groundwater pumping, a record should be kept of the start and end time of groundwater pumping, the flow rate (measured multiple times during the pumping

period), and the time of influent and effluent sampling. The influent and effluent samples should be recorded on the COC form by time as is standard procedure for most groundwater samples collected for routine analyses.

2.2.6 Relevant Blanks for Perchlorate Sampling

When volatile organic compounds (VOCs) or other contaminants are sampled by grab methods, a series of different blanks are often collected, including field blanks, equipment blanks, filter blanks, and trip blanks (e.g., see Keefe et al., 2003). Most of these blanks are designed to determine if sampling procedures or equipment have caused cross-contamination of samples or if background contamination exists in sample bottles or preservatives. Because of the unique nature of sampling ClO_4^- for isotopic analyses, which employs IX columns (rather than sample bottles) to collect milligram quantities of ClO_4^- from hundreds to thousands of liters of water, trace contamination with ClO_4^- is unlikely to affect results. This is in contrast to many other methods, such as VOC sampling, where contamination of a sample or bottle with 1 μg/L of a chemical is often important and needs to be identified. Moreover, many of the types of blanks used for typical grab sampling for concentration are not easily transferred to the IX method used for isotope samples. For this reason, blank samples typical of VOC or other sampling are not generally used or deemed necessary in ClO_4^- sampling for isotopic analyses.

However, based on current methods, the following guidance is provided on the potential application of blank samples for field projects involving sample collection for Cl and O isotopic analyses of ClO_4^-:

1. Field Blank. Field blanks are often used to determine if contamination exists in sample bottles or bottle preservatives. The blanks are filled with certified contaminant-free water in the field and analyzed in the analytical laboratory for contamination. This approach is applicable and recommended in instances where ClO_4^- concentrations of the order of milligrams per liter are present in groundwater and samples are shipped to the laboratory in bottles rather than adsorbed in IX columns. For reasons noted above, it is difficult to determine how to prepare an appropriate field blank when IX column sampling is conducted because hundreds to

thousands of liters of water are passed through the column in the field. It is not practical to simulate this process in the field using ClO_4^--free water due to the volumes required. Thus, this type of blank is not currently deemed necessary. An equipment blank (see below) can be used to ensure that the columns or resin do not contain ClO_4^- prior to sample collection.

2. Equipment/Rinse Blank (Analytical Procedure Blank). An IX column equipment blank can be prepared to ensure that the IX resin or column sampling device are not contaminated with ClO_4^-. To prepare this blank, one column that is manufactured along with those used to collect ClO_4^- from groundwater at a site should be preserved and processed with the other sample columns. No groundwater should be passed through this column prior to processing. ClO_4^- should not be present above trace level in the extract from this column (< 10 μg total recovered). In addition to this approach, ClO_4^- can be measured in each lot of Purolite A530E resin that is used to prepare sampling columns to ensure that the resin is free of ClO_4^-. Because this resin is certified for use in drinking water treatment systems for ClO_4^-, and it is not recycled, contamination of virgin resin with ClO_4^- is unlikely.

   In addition, good management practices should be used when transferring a submersible pump between wells, including thoroughly decontaminating the pump with clean (ClO_4^--free) water and either thoroughly washing or replacing the tubing. However, because ClO_4^- does not adsorb in most tubing material, and is completely soluble, the risk of significant contamination of an isotope sample due to carry-over between wells is minimal. Thus, equipment blanks from pumps can be taken to ensure good management practices are followed, but they are not critical for ClO_4^- sampling for isotopic analyses.

3. Trip Blank. A trip blank is generally prepared in the laboratory using analyte-free water, shipped with the sample containers to the field, and then returned to the laboratory unopened to assess sample contamination during transport. For isotopic analyses, the approach previously described for an IX column equipment blank

should also be sufficient as a trip blank, if the column is transported with all other sampling columns to the field but not used in sampling activities. As previously noted, the potential for an IX sampling column to become inadvertently contaminated with a quantity of ClO_4^- large enough to affect isotope results during shipping or routine well sampling is considered highly unlikely.

2.2.7 Summary of QA/QC Procedures for Groundwater Sampling

The following is a summary list of basic QA/QC procedures used to sample ClO_4^- for O and Cl isotopic analyses that have been covered in the previous section.

1. Each IX column should be individually tagged or marked with permanent ink and the column identifier should be recorded in a field book and a COC form for each well sampled.
2. Duplicate columns should be collected for an individual groundwater well when possible.
3. A meaningful field blank is not practical when using an IX column for sampling, but can be prepared in instances where water samples (rather than IX columns) are shipped. An equipment blank can be prepared by extracting and analyzing ClO_4^- from an IX column that has not been used in the field for sampling.
4. Each groundwater well should be purged according to accepted procedures for an individual site as outlined in Section 2.2.2 prior to sampling.
5. The column should be operated in an upright position at $\leq$ 2 L/min and the flow rate should be recorded and adjusted periodically during the collection time. Influent and effluent samples should be collected from each column periodically for subsequent analysis of ClO_4^- concentration.
6. Once sampling is complete, columns should be drained, and the ends sealed with a single piece of tubing. The sealed column should then be sealed in a Ziploc style bag and placed at 4 °C. Shipping to the analytical laboratory should be done on ice prior to ClO_4^- extraction and analysis.
7. Additional column preservation by saturating the resin with 0.05 M HCl is recommended if ClO_4^- is collected from an anoxic aquifer or location where biodegradation is likely or if extended storage is expected (e.g., archived sample).

The column should be sealed in a Ziploc style bag and placed at 4 °C after preservation with HCl.

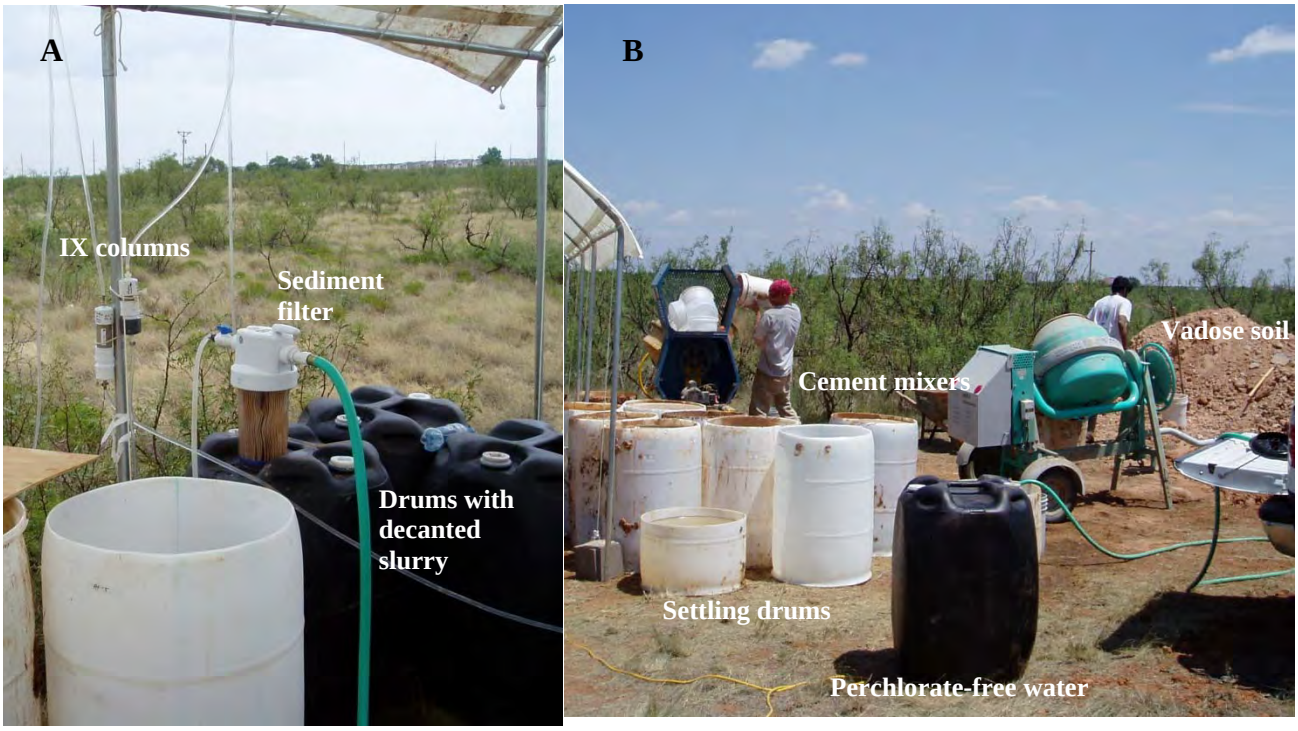
2.2.8 Soil Sampling Procedures

Perchlorate for isotopic analysis can be extracted from solid samples of surficial salt deposits, surface soils, and the deep vadose zone. The basic procedure for collection was described recently by Jackson et al. (2010). Initially, the concentration of ClO_4^- in the bulk material should be determined by collecting several solid samples, extracting soluble salts from the samples with ClO_4^--free water, and then measuring the ClO_4^- concentration by an accepted analytical method for soils (e.g., USEPA, 2007). The total amount of solid material that must be extracted (leached) to collect the required milligram quantities of ClO_4^- for purification and isotopic analysis can then be determined. Because ClO_4^- is highly soluble in water, it can be removed readily from dispersed solids by aqueous leaching. Vadose-zone material containing ClO_4^- can be collected using a backhoe, placed on a tarp or other clean surface to isolate it from surrounding soils, and extracted with ClO_4^--free water (Jackson et al., 2010). It is important to remove any ClO_4^- from the water source used for solid extraction, which can be accomplished by initially passing that water through a large column of Purolite A530E resin prior to use, as described in Jackson et al. (2010).

Extraction of ClO_4^- from solids can be conducted in small batches by adding solid material (40 to 60 kg) and water (~ 80 L) in a clean cement mixer, mixing the slurry for ~10 min, then decanting the liquid into a large polyethylene drum or other container (Figure 2.4). After sediments settle in the drums, the overlying water (with dissolved ClO_4^-) is pumped to a clean container, then passed through a sediment pre-filter (e.g., 50-μM pore-size; General Electric Co., Trevose, PA) and an IX resin column in sequence, as described previously for groundwater sampling (see Fig 2.3 & 2.4). Influent and effluent samples should be collected periodically to determine the concentration of ClO_4^- in water applied to the column and the efficiency of ClO_4^- removal as described for groundwater in Section 2.2.2. After the extraction process, basic QA/QC procedures described for groundwater sampling are applicable. In addition to these procedures, it is advisable to wash any

equipment used for soil mixing and to determine that the vessels are free from outside contamination with ClO_4^- by analyzing rinse water. It should be noted that for ClO_4^- at low microgram-per-kilogram concentrations in solid material, extraction of several thousand kilograms of solids may be required to obtain sufficient ClO_4^- for Cl and O isotopic analyses.

Figure 2.4. Extraction of ClO_4^- from vadose-zone sediment in West Texas. (A) Collection of ClO_4^- from decanted soil extracts on IX columns after passing through a sediment filter. (B) Extraction of ClO_4^- from soil by slurrying in cement mixers. (*see* Jackson et al. 2010 for further details).



2.3 Extraction and Purification of Perchlorate on IX Columns

2.3.1 Overview of Procedures

The second step after collection of ClO_4^- in the field is extraction of the adsorbed ClO_4^- from the IX resin and separation of the ClO_4^- from other compounds that also have some affinity to the IX resin, including nitrate (NO_3^-), sulfate (SO_4^{2-}), bicarbonate, (HCO_3^-), and a range of humic and(or) other organic compounds and clays. Depending on the environmental source and location of the sample, other compounds, including perrhenate (ReO_4^-) and chlorate (ClO_3^-) may also be present on the resin, and in urban areas, surfactants and detergents commonly are adsorbed. A simple process utilizing ferric chloride ($FeCl_3$) and hydrochloric acid (HCl) has been developed to remove ClO_4^- from the bifunctional anion exchange resin, primarily by generating tetrachloroferrate ($FeCl_4^-$), which effectively displaces ClO_4^- on adsorption sites (Gu et al., 2001, 2007; Gu and Brown, 2006). However, the subsequent steps required to purify the extracted ClO_4^- from the complex mixture of residual $FeCl_3$, anions, and organic compounds removed from the resin, are both labor intensive and somewhat variable in nature depending on the anions and other chemicals in the extract. This phase of the process, which includes various precipitation, selective adsorption, and filtration steps has been the subject of significant research and development during the past few years. Additional development is ongoing as more difficult samples are processed (e.g., plant extracts, seawater, lake water, soils). The purification methods described in this section, which are current best practices, are likely to be refined and improved in the coming years.

2.3.2 Resin Removal from IX Columns and Resin Pre-Wash

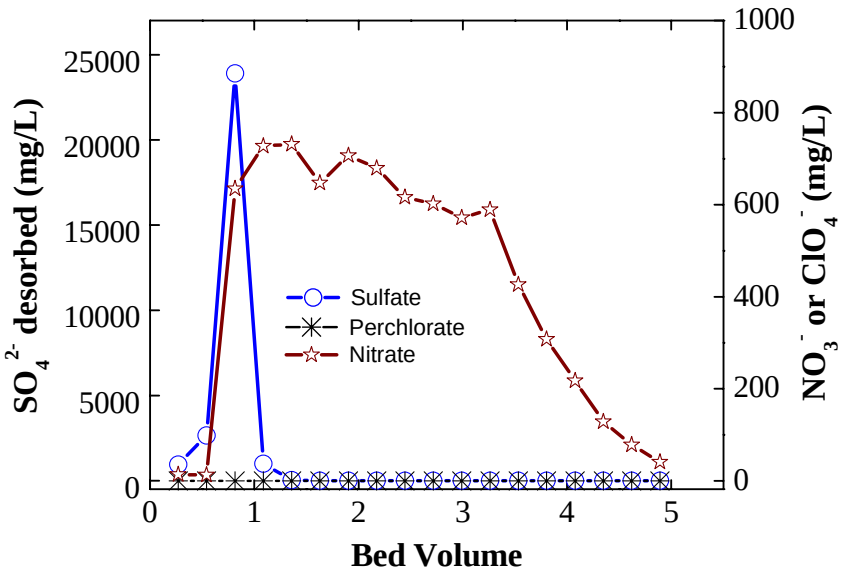
The field sampling columns depicted in Figure 2.1 are compatible with the 4 M HCl used for resin extraction (as described in the next paragraph) provided that Teflon screens (rather than stainless steel) are used in construction. Direct extraction of these columns (with Teflon) to elute ClO_4^- is therefore possible without removing the resin. However, because the PVC IX columns are designed to process a large volume of water at a high flow rate, the initial step in ClO_4^- removal is generally to transfer the IX resin (with adsorbed ClO_4^-) from the field sampling column (Fig 2.1-2.3) into a preparative glass chromatography column (100 mL volume) fitted with Teflon end-plugs (e.g., Omnifit, Boonton, NJ; https://www.biochemfluidics.com/pdf/Columns.pdf). These chromatography columns can

be tightly packed with the IX resin to ensure plug flow during extraction (and high washing efficiency) as settling of resin sometimes occurs in IX columns after field use. Multiple columns can be used if necessary (e.g., if a larger field resin column is used). To transfer the resin from a typical 100-mL field column, the screw-on end cap (Item F; Fig 2.1) should be unscrewed and the screen on top of the resin removed. The resin can then be carefully removed with a clean spatula and a small amount of water (or groundwater left in the column) and transferred to the glass preparative column. The glass columns should be labeled in accordance with accepted laboratory COC procedures. [An intermediate step involving rinsing with ultrapure deionized water in an ultrasonic bath after removal from the field column and before transfer to the glass preparatory column, may be advisable at this point if the resin exhibits a substantial discoloration or presence of fine sediment. Several rinses may be needed to obtain a clear rinse solution before proceeding to the glass preparative column.

After the resin has been packed into the glass preparatory column, it should then be washed with ~ 5 bed volumes (BV) of 4 M HCl. The HCl solution removes much of the adsorbed SO_4^{2-}, NO_3^-, HCO_3^-, and some of the humics, but does not desorb ClO_4^- which is more strongly held by the bifunctional resin than most other anions or organics. A typical elution profile from a preparative column packed with resin is provided in Figure 2.5. It is clear in this figure that SO_4^{2-} ions elute quickly with nearly all SO_4^{2-} removed from the resin with only 1 BV of HCl solution. The NO_3^- desorbs more slowly, and small amounts are still observed in the effluent after leaching with 5 BV of the HCl solution. However, the process removes a majority of the NO_3^- on the IX resin column. The 4 M HCl also removes a significant fraction of the organics and carbonates when they are present on the resin. Although it is difficult to monitor for organics in the effluent solution, a “brownish” color of the initial solution eluting from the column is evidence of their presence in the HCl. Carbonates will be removed primarily as CO_2 gas evolution from the acidic solution. During the pre-wash, effluent samples should be collected and analyzed for ClO_4^- using one of the currently accepted methods (USEPA, 2009) to ensure that no significant loss occurs during the washing procedure. Analyses of other competing anions, such as SO_4^{2-}

and NO_3^- can also be performed on effluent samples from the pre-wash (using EPA method 300.0; USEPA, 1993) to ensure adequate removal of these species.

Figure 2.5. Elution profiles of SO_4^{2-}, NO_3^-, and ClO_4^- from IX columns using 4 M HCl as an extractant. The number of bed volumes of HCl is given on the x-axis.



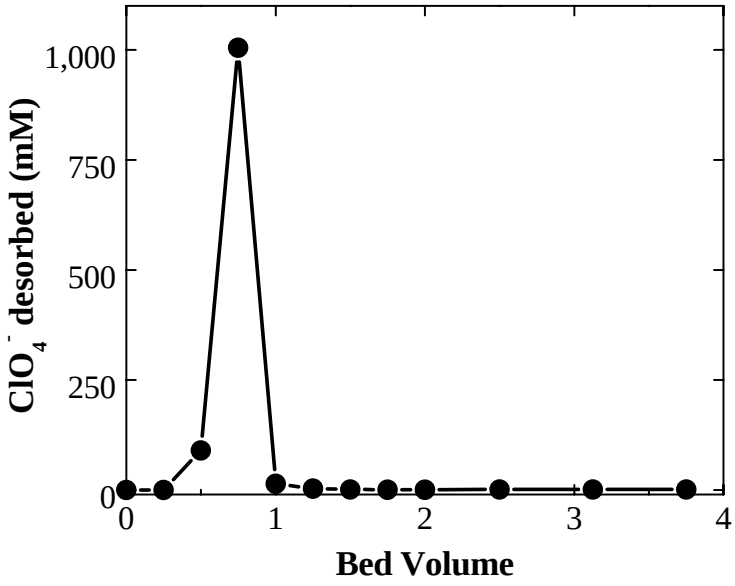
2.3.3 Perchlorate Elution and Analysis

The preparative column (Section 2.3.2) is next eluted with a combination of 1 M $FeCl_3$ and 4 M HCl to remove adsorbed ClO_4^- (Gu et al., 2001, 2007, 2011). When the $FeCl_3$ is mixed into an excess of Cl^-, tetrachloroferrate ($FeCl_4^-$) ions form at equilibrium according to Equation 2.2:

[Eq. 2.2] $$FeCl_3(aq) + Cl^- \rightleftharpoons FeCl_4^-$$

The $FeCl_4^-$ ion is chemically similar to ClO_4^-, each being large, poorly hydrated, tetrahedral anions. Because of their physicochemical similarities, $FeCl_4^-$ effectively displaces ClO_4^- from the bifunctional IX resin, and only a small number of bed volumes of the solution are required to completely desorb the resin-bound ClO_4^-. During the desorption process, 2 or more BV of the $FeCl_4^-$ solution should be run through the column and collected. Effluent may be collected at 0.1 to 0.25 BV intervals using a standard fraction collector with clean glass test tubes, and ClO_4^- concentration determined for each fraction. Because ClO_4^- elutes from the column as a sharp peak within ~ 1 BV (Fig 2.6), the total volume of eluent used for further ClO_4^- purification steps can be minimized by processing only the collected fractions containing ClO_4^-. The ClO_4^- concentration in each fraction of the effluent should be analyzed using EPA Method 314.0 (USEPA, 1999) or an alternative accepted method (USEPA, 2009). The total amount of eluted ClO_4^- should then be determined using the concentration and volume of each fraction. The effluent fractions containing ClO_4^- should then be combined into a single sample for further processing, as described in the next section.

Figure 2.6. Elution of ClO_4^- from IX resin using $FeCl_4^-$ solution. The number of bed volumes of extractant is given on the x-axis.



2.3.4 Effluent Clean-up and Concentration of Perchlorate

Two somewhat different approaches have been developed to recover ClO_4^- from the HCl-$FeCl_3$ eluent solution (Section 2.3.3). These alternative approaches, the first of which was developed at Oak Ridge National Laboratory (ORNL) and the second at the University of Illinois at Chicago (UIC), utilize different techniques to remove abundant quantities of Fe (from the $FeCl_3$-HCl eluent) from solution. Each approach has advantages and disadvantages. Initial studies comparing the two approaches, which are described below, suggest that they provide comparable isotope data (unpublished data, ESTCP Project ER-200509). Additional development and verification work on these procedures is ongoing.

2.3.4.1 Iron Removal using Neutralization and Precipitation

The raw eluent solution containing ClO_4^- also contains a high concentration of Fe, as well as a mixture of other anions and organics. A pure ClO_4^- salt must be obtained from this mixture. The ORNL approach to remove Fe and other impurities entails initial neutralization of the acidic eluent with sodium hydroxide (NaOH) in a glass beaker to achieve a pH between 9 and 10. At this alkaline pH, the Fe in solution precipitates primarily as $Fe(OH)_3$ (red-brown precipitate) with the ClO_4^- remaining in the clear solution. The $Fe(OH)_3$ precipitates usually are separated by centrifugation at 6000 rpm for about 10 min, and clear supernatant solution is collected. The precipitates are washed once with deionized (DI) water, re-centrifuged, and clear supernatant solution is again collected (or combined). Alternatively the $Fe(OH)_3$ precipitates can be separated by filtration (0.45 μm) and washing with deionized (DI) water under vacuum. The eluent is collected to recover ClO_4^-.

The resulting clear supernatant solution with ClO_4^- is then concentrated using a vacuum concentration system, such as a SpeedVac Concentrator (Savant Instruments, Holbrook, New York). The SpeedVac system centrifuges samples under vacuum to evaporate liquids. During evaporation, precipitates (mainly Na salts) should be removed periodically by filtration or by decanting the clear liquid away from them. The amount and type of precipitate will vary based on the impurities in each sample. The evaporative process should continue until the estimated ClO_4^- concentration in solution (based on estimates in the $FeCl_3$-HCl eluent) is in excess of 3 mg/mL. The degree of concentration required is

based on the starting ClO_4^- concentration, and can exceed 100-fold for dilute solutions (i.e., due to low quantities of ClO_4^- on the resin). This high concentration of ClO_4^- is necessary to crystallize ClO_4^- salts in a final step (see Section 2.3.5). The concentration process can result in significant losses of ClO_4^-, particularly if large quantities of precipitate must be removed (as some ClO_4^- can be trapped in the precipitates or in liquid removed with the precipitates). The salts recovered during this process should be saved, and if losses of ClO_4^- are high, these salts can be re-dissolved in ClO_4^--free water. The resulting aqueous solution can then be passed over a small glass preparative column packed with Purolite A530E resin (e.g., 5 mL preparative column) to remove ClO_4^-. The ClO_4^- can then be desorbed from the resin and recovered using procedures described previously beginning in Section 2.3.2. The resulting extract can be combined with the primary extract to increase the quantity of ClO_4^- recovered.

2.3.4.2 Iron Removal using Ion Exchange

The second approach for ClO_4^- recovery, developed at UIC, utilizes cation exchange resin rather than pH adjustment to remove Fe^{3+} ions from the column eluent. After evaluation of several different resins, Bio-Rad AG-50W-X12 resin, 100-200 mesh (Bio-Rad Co., Hercules, California), was selected for this application. The main advantages of this protocol are that the Fe is removed without forming large quantities of $Fe(OH)_3$ precipitate and that large amounts of Na are not added. The main disadvantage of this process is the potential loss of ClO_4^- from adsorption onto the cation-exchange resin, despite the fact that both are negatively charged. Some resins can result in >35 % loss of ClO_4^-, thus the AG-50W-X12 resin is recommended for this application. Using this protocol, the $FeCl_3$-HCl eluent with dissolved ClO_4^- is passed through a large glass column packed with 600 mL of the AG-50W-X12 resin. The eluent is then collected and subjected to evaporation on a hot plate, with addition of 2 mL concentrated H_2O_2 to oxidize organic compounds, until 25 mL of solution remains (> 3 mg/mL ClO_4^-). The evaporation of this azeotropic mixture (~6 M HCl) removes most of the excess HCl without any precipitation of NaCl or other Na salts. To separate residual NO_3^- from the ClO_4^-, the concentrated sample is reloaded onto 1 mL of A530E resin, flushed with 4 M HCl, re-eluted with $FeCl_3$-HCl, and the resulting eluent evaporated to <5 mL. The remaining excess dissolved Cl^- (HCl) is then removed by passing the sample through an OnGuard II Ag Sample Pretreatment Cartridge (Dionex,

Sunnyvale, California). OnGuard II H (cation-exchange hydronium form resin) cartridges are then used to remove any dissolved Ag^+. In unpublished tests from ESTCP ER-200509, the presence of Ag^+ was shown to fractionate oxygen isotopes during combustion (Section 2.4). The purity of the resulting ClO_4^- is evaluated by ion chromatography for the presence of other anions (see Section 2.3.6.2). At this stage, residual organics are removed by oxidation with pure H_2O_2 or by Strata SDB-L (Phenomenex, Torrance, California) solid phase extraction.

2.3.5 Perchlorate Crystallization and Recovery

The final step in sample processing is crystallization of ClO_4^- as a salt. Prior to this step, it is important to check that no other precipitates are present in the final concentrated extract (> 3 mg/mL ClO_4^-). If precipitates are observed, they should be removed via filtration. The concentrated ClO_4^- in the solution can be crystallized as rubidium perchlorate ($RbClO_4$) by adding RbCl, as cesium perchlorate ($CsClO_4$) by addition of CsCl or CsOH, or as potassium perchlorate ($KClO_4$) by addition of KOH or KCl. Most of the environmental samples for which published results are available have been prepared as $CsClO_4$ (See Appendix A, Table A-1), One approach to precipitate ClO_4^- as $CsClO_4$ (used at ORNL) is to add CsCl to ClO_4^--free water to form a saturated solution, and then add this solution dropwise to the clear extract with ClO_4^- to cause super-saturation (i.e., to form $CsClO_4$ precipitates). In general, a higher initial ClO_4^- concentration in the extract will yield higher recovery and more rapid precipitate formation. Theoretically, at a ClO_4^- concentration of 100 mg/mL, > 99 % of the ClO_4^- should precipitate as $CsClO_4$ salt compared to ~ 98 % if KCl is used (Gu et al., 2011). Lower recovery may be observed when handling small volumes and(or) lower concentrations of ClO_4^-. For example, at a ClO_4^- concentration of 5 mg/mL and a small volume (< 1 mL), recoveries of < 60 % were observed in the laboratory (Gu et al., 2011). For this reason, it is important to collect as much ClO_4^- as possible during the sampling phase, as described in Section 2.2. The UIC procedure now exclusively precipitates $KClO_4$, to better match the $KClO_4$ isotopic reference materials, by adding an excess of KOH to the liquid sample after ion exchange clean-up (Section 2.3.4.2), and then to slowly evaporate the liquid. Residual KOH is removed from $KClO_4$ by rinsing the residue with methanol.

After crystallization of the ClO_4 salt is observed, the crystals should be collected by filtration, and the liquid saved and analyzed for residual ClO_4^-. The crystals should next be rinsed with a few drops of 90 % methanol (by volume, in water) to ensure that surface of the crystallized ClO_4 salt is free from other salts. The salts should then be carefully collected and placed in a clean glass vial for assessment of purity as described in Section 2.3.6.

2.3.6 Assessing Purity of Recovered Perchlorate Crystals

To ensure that the recovered $CsClO_4$ (or $KClO_4$) is of the highest purity for IRMS, the recovered ClO_4^- salts should be examined using one of two techniques: (1) non-destructive Raman spectroscopy or (2) dissolution and analysis by ion chromatography (IC) using USEPA Method 300.0 (USEPA, 1993) or equivalent. For large samples, both techniques can be used. Among the most common potential contaminants containing O are NO_3^- and SO_4^{2-}. ReO_4^- has also been identified in a subset of samples (Gu et al., 2011). It is desirable that impurities in the ClO_4^- salt comprise no more than 1 % of the total O in the sample on a molar basis (i.e., the mole fraction of O in the sample that is not attributable to ClO_4^- should be less than 0.01) in order to minimize any effects on O isotopic analysis. On a mass basis, this would correspond to approximately 0.02 mg of NO_3^- or 0.03 mg of SO_4^{2-} per mg of ClO_4^-. Organic compounds, including surfactants and humics, also are sometimes residual contaminants in purified samples if organic removal and oxidation steps are not 100 % effective, particularly in samples from urban sources (surfactants) or surface-water samples and vadose-zone sediment extracts (humics). These compounds can react with O_2 released during ClO_4^- decomposition, generating CO_2 and causing O isotopic fractionation. The CO_2 peak can be monitored when analyzing O_2 produced by ClO_4^- decomposition to determine the level of contamination with organic C as described in Section 2.4. The impurity most likely to affect the Cl isotopic composition of recovered ClO_4^- is Cl^-. Chloride in solution during final precipitation of ClO_4^- salt by the ORNL method is efficiently excluded during the process, but care must be taken to ensure that residual Cl-rich liquid or NaCl is not included in the ClO_4^- product. The UIC method removes Cl^- prior to final precipitation of the ClO_4^- salt. Following either method, absence of Cl^- in the final product can be confirmed by IC.

2.3.6.1 Raman Spectroscopy

Micro-Raman spectroscopy is a non-destructive technique, which is advantageous for analyzing small samples (such as a single crystal) of $CsClO_4$ or $KClO_4$. The technique is commonly used to study vibrational frequency modes in a given molecule, and it relies on inelastic Raman scattering of monochromatic light, usually from a laser (Gu et al., 2009). The laser light interacts with molecules, resulting in the energy of the laser photons being shifted up or down, and this shift in energy gives information about the vibrational modes of the molecule. This Raman shift, which is characteristic of a pure compound, can thus be used to evaluate the purity of a solid, liquid, or gas using filters and a specialized detector (e.g., photodiode array detector). Background or inconsistent Raman shift patterns or peaks are indicative of impurities in a sample. Further details on Raman spectroscopy can be found in Smith and Dent (2005) and Gu et al. (2009).

To evaluate the purity of $CsClO_4$ (or $KClO_4$), Raman spectra should be collected from at least 2 to 3 single $CsClO_4$ crystals using a Raman Imaging Microscope and spectrometer. The $CsClO_4$ crystals should exhibit needle-shaped morphologies, and they should have characteristic Raman bands at 937, 627, 460 cm^{-1}, respectively, the strongest band at about 937 cm^{-1} (Figure 2.7) (Gu et al., 2009, 2011). In addition, there are double bands at 1110 and 1085 cm^{-1}, a shoulder next to the 937 cm^{-1} band, and two minor bands between the 460 and 627 cm^{-1} bands. All of these bands should be present in the Raman spectra; any other peaks or peak shifts are indicative of impurities in the sample. Cubic or spherical shaped crystals usually indicate impurities such as NO_3^- or SO_4^{2-} salts, which can be detected by Raman spectroscopy with characteristic Raman shifts at 1050 cm^{-1} (for NO_3^-) and 980 - 985 cm^{-1} (for SO_4^{2-}) as shown in Figure 2.8. Pure $CsClO_4$ solids should exhibit smooth baselines (similar to the reagent $CsClO_4$ in Figure2.7) with no visible Raman bands at 1050 or 980 cm^{-1}. At concentrations less than those illustrated in Figure 2.8, these impurities will have relatively little effect on the isotopic analysis of the $CsClO_4$. Broad and high background usually suggests the presence of impurities such as organics and other salts. In addition, as previously noted, a subset of samples from the Southwest has been observed to contain perrhenate (ReO_4^-), with visible spectral bands at 970 and 332 cm^{-1}. Rhenium (Re) is a very rare metal, but the most oxidized form, ReO_4^-, behaves similarly to ClO_4^-.

Currently, the two anions cannot be separated, and samples with high ReO_4^- have not yet been analyzed for Cl and O isotopic composition. Thus far, substantial amounts of ReO_4^- have been found only in a few samples collected from mineral deposits in the Death Valley region; ReO_4^- was either absent, or present only at insignificant trace levels, in more than 100 other samples analyzed to date from other regions (Gu et al., 2011). Experiments are ongoing to determine methods to remove ReO_4^- from samples in which it occurs.

Figure 2.7. Raman spectrum of $CsClO_4$. Characteristic Raman bands are observed at 937, 627, 460 cm^{-1}.

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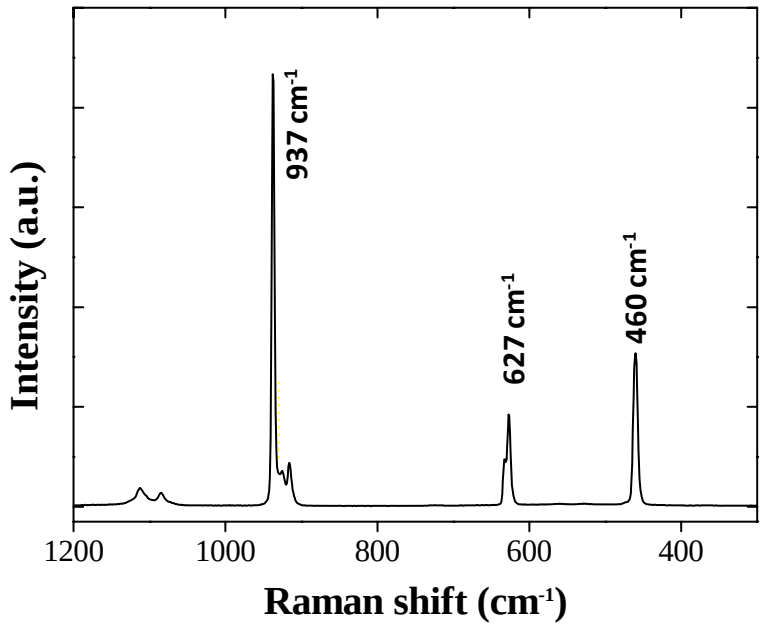
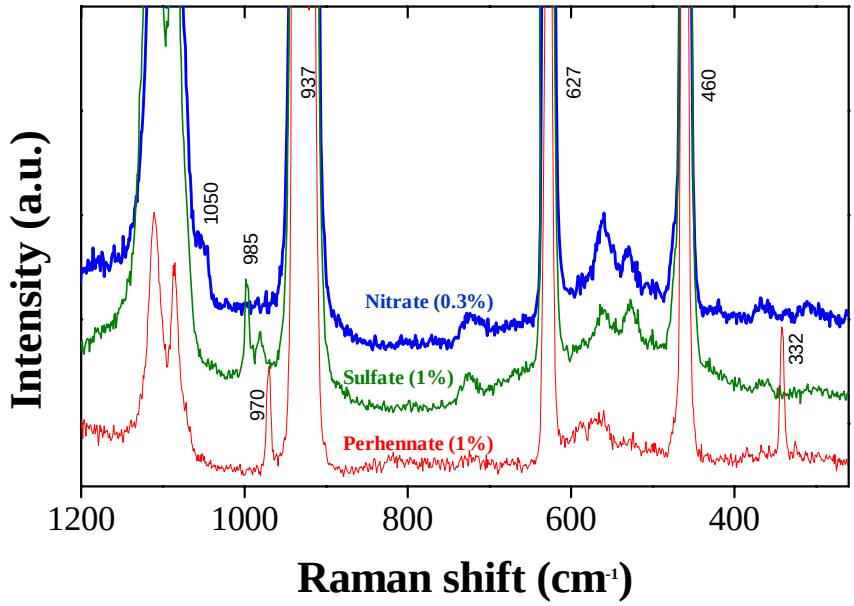


Figure 2.8. Raman spectra of $CsClO_4$ contaminated with ~ 0.3 % NO_3^-, 1 % SO_4^{2-}, or 1 % ReO_4^- (by mass) compared to pure $CsClO_4$. Corresponding mole fractions of O atoms from the contaminants in the mixtures are approximately 0.8 %, 2.4 %, and 0.9 % for NO_3^-, SO_4^{2-} and ReO_4^-, respectively. The broad and high background spectra as well as characteristic bands for NO_3^-, SO_4^{2-}, and ReO_4^-, respectively, reveal the presence of impurities in the sample. The y-axis is in relative arbitrary units (a.u.)



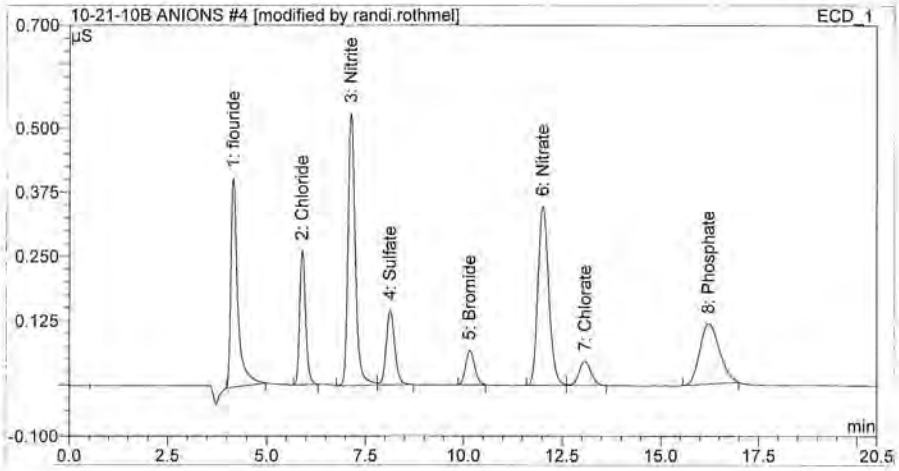
2.3.6.2 Ion Chromatography

If sufficient quantities of ClO_4^- are obtained during sample processing and purification, ion chromatography (IC) using EPA Method 300.0 (USEPA, 1993) can be used to detect the most common impurities, including NO_3^- and SO_4^{2-}. However, this process is destructive, and a small quantity of the sample must be sacrificed. Various methods can be used for IC based on sample size. For large samples (> 5 mg), ~ 1 mg of the $CsClO_4$ salt can be weighed and dissolved in 5 mL of DI water (volume required for typical IC analysis), which will result in a ClO_4^- concentration of ~ 85 mg/L. The presence of 0.8 % NO_3^- and 1.0 % SO_4^{2-} by mass, which is equivalent to a mole fraction of O of ~ 0.01 from these impurities (where mole fraction of O from impurity is [mol O from impurity] / [mol O from ClO_4^- plus impurity]), would result in concentrations of ~ 0.70 and 0.85 mg/L of each, respectively, which are readily detectable by EPA Method 300.0 (MDL for each of these anions is ~ 0.1 to 0.2 mg/L). A typical chromatograph for EPA Method 300.0 with all constituents at 0.2 mg/L is shown in Figure 2.9. As observed in the figure, other oxygen-containing species including phosphate (PO_4^{2-}), chlorate (ClO_3^-), and nitrite (NO_2^-) can also be detected by this method, as well as Cl^-. ClO_4^- is not detected by USEPA 300.0 and should be analyzed by USEPA 314.0 or equivalent. For small samples (i.e., < 5 mg), the entire processed sample (or a portion sufficiently large weighed accurately) can be dissolved in DI water to give a final concentration of ~ 0.3 - 0.6 mg/mL as ClO_4^-, and then a 200-μL aliquot of that aqueous sample (~ 60 - 120 μg ClO_4^-) can be dissolved in DI water and analyzed by IC. The technique will again provide the required MDL 0.1 to 0.2 mg/L of each potential contaminating anion required to evaluate purity at the level of 0.01 mole fraction of contaminant O.

Figure 2.9. Typical ion chromatogram from EPA Method 300.0 for various anions at concentrations of approximately 0.2 mg/L in an aqueous sample.

Sample Run ID:	0.2ppm	**Sample No.:**	4
Sample ID:		**Sequence Name:**	10-21-10B ANIONS
Program Method:	EPA 300 KOH	**Injection vol.:**	25.0
Quantitation Method:	EPA300(KOH)	**Dilution Factor:**	1.0000
Date Time Collected:	10/22/2010 10:45 AM	**Sample Wt.:**	1.0000
System Operator:	randi.rothmel	**Sample Amt.:**	1.0000

Peak No.	Component Name	Retention Time	Area µS*min	Height µS	Amount ppm	Amnt.Dev.(rel) %	Relative Amount %
1	flouride	4.15	0.082	0.407	0.1822	-8.8981	12.16
n.a.	Chlorite	n.a.	n.a.	n.a.	n.a.	n.a.	n.a.
2	Chloride	5.90	0.045	0.261	0.1800	-10.0196	12.01
3	Nitrite	7.14	0.115	0.530	0.2030	1.5185	13.55
4	Sulfate	8.13	0.037	0.145	0.1762	-11.8839	11.76
5	Bromide	10.16	0.018	0.067	0.1551	-22.4462	10.35
6	Nitrate	12.02	0.111	0.348	0.1766	-11.7093	11.79
7	Chlorate	13.08	0.017	0.047	0.1576	-21.2097	10.52
8	Phosphate	16.23	0.069	0.117	0.2675	33.7419	17.85



2.3.7 Reprocessing Impure Samples

If impurities are identified in a purified sample of $CsClO_4$ (or $KClO_4$) by Raman spectroscopy and(or) IC at concentrations appreciably greater than 1 % of the total O in the sample on a molar basis (as described in Section 2.3.6), the sample may be further purified by re-dissolving in ClO_4^- -free distilled deionized water (DDI), re-precipitating by evaporation, and rinsing with a small amount (e.g., 1 drop) of methanol or H_2O_2 solution, until satisfactory purity is achieved. In some instances, depending on the type of contaminant, it may be beneficial to pass the aqueous solution with ClO_4^- thorough a small (e.g., 5-mL volume) glass preparative column with A530E resin so that the ClO_4^- is selectively adsorbed in the resin. The resin can then be re-processed by washing with HCl to remove impurities as described in Section 2.3.2. The ClO_4^- should then be eluted and purified as described previously in Sections 2.3.2 – 2.3.6. The samples may have to be reprocessed more than once if elevated levels of impurities are detected, which is most common for samples obtained from soils, mineral extracts, or surface water bodies (e.g., Great Lakes; ESTCP Project ER-200509, unpublished data). When impurities are detected at concentrations corresponding to < 0.01 for the mole fraction of O in the sample by Raman spectroscopy and(or) IC, the sample is ready for Cl and O isotopic analyses by IRMS as described in Sections 2.4 and 2.5, respectively.

2.3.8 QA/QC Considerations for Perchlorate Elution and Purification

A summary of relevant QA/QC considerations for ClO_4^- elution and purification are provided in this section.

The following QA/QC procedures are recommended:

1. All chemicals used for washing and resin regeneration (e.g., HCl, NaOH, and $FeCl_3$) should be of analytical reagent grade and ClO_4^--free.

2. Water used to make solutions should be tested to be ClO_4^--free (< 0.1 μg/L) or passed through A530E IX resin prior to use to remove ClO_4^-.

3. Use of reagent blanks is recommended during sample processing.

4. All containers to which an individual sample is transferred should be properly labeled and documented according to established laboratory COC procedures.

5. An unused IX resin column (Equipment Blank), as described in Section 2.2.6, and(or) a sample of virgin A530E resin can be processed with field samples to ensure that there is no contamination with ClO_4^- during sample collection, shipping, or processing. ClO_4^- should not be detected at any time in samples prepared from the field blank or unused resin at amounts > 10 μg/60 g dry mass.

6. An internal control sample can be prepared in the laboratory by dissolving 10 mg of $KClO_4$ or $NaClO_4$ salt with a known isotopic composition in 1 L of DI water, and passing that water through an IX resin column to trap the dissolved ClO_4^-. This column can then be processed with the field sample columns from a site. The O and Cl isotopic composition of ClO_4^- from the control column should be the same as that of the parent salt (± expected analytical variability). Any isotopic fractionation due to sample processing (e.g., due to precipitation) can be documented in this way, and corrections can be made to field samples if required.

7. Raman Reference Standards: Reagent $CsClO_4$ and/or $KClO_4$ should be used as a reference standard for Raman analysis, matching the final form of the field samples.

8. Typical standards and blanks for USEPA Methods 300.0 and 314.0 should be analyzed as described previously (USEPA, 1993).

2.4 Analysis of Oxygen Isotopes in Perchlorate by IRMS

After the $CsClO_4$, $RbClO_4$, or $KClO_4$ is purified according to the procedures described in Section 2.3, it is analyzed for O and Cl isotopic composition by IRMS according to the procedures described in Section 2.4 (this section) for O and Section 2.5 for Cl. Abbreviated descriptions of methods and calibrations of O isotopic analyses have been published previously in several papers and book chapters as described in Section 2.1. Additional publications describing the procedures used for production and calibration of ClO_4^- isotopic reference materials, along with additional information about analytical methods, are in preparation. The current summary, therefore, represents the current state-of-the art, but is subject to modifications and(or) updates in the future.

Analysis of O isotopes in ClO_4^- can be conducted by two different methods, both of which are described in the following sections. The first method entails conversion of alkali perchlorate salts to alkali chloride salts plus O_2 gas. The values of $\delta^{18}O$ and $\delta^{17}O$ can each be measured by decomposing $CsClO_4$ (or $RbClO_4$ or $KClO_4$) to yield a stoichiometric quantity of O_2 according to the reaction:

$$CsClO_4 \rightarrow CsCl + 2O_2$$

The O_2 gas is then admitted to a magnetic-sector type, dual-inlet isotope-ratio mass spectrometer (DI-IRMS) and analyzed by monitoring *m/z* 32 ($^{16}O^{16}O$), 33 ($^{17}O^{16}O$), and 34 ($^{18}O^{16}O$, plus an insignificant contribution from $^{17}O^{17}O$). Yields of O (as O_2) by this method are typically within ±5 % for pure ClO_4^- salts. Method details and QA/QC considerations are provided in Section 2.4.2. Analysis of $\delta^{18}O$ (but not $\delta^{17}O$) also can be done by reacting the ClO_4^- salt with glassy C to produce CO, which is then transferred in a He carrier through a molecular-sieve to a continuous-flow IRMS (CF-IRMS) and analyzed by monitoring peaks at *m/z* 28 ($^{12}C^{16}O$) and 30 ($^{12}C^{18}O$, plus an insignificant contribution from $^{13}C^{17}O$). Yields of O (as CO) typically are 100 ±2 % for pure ClO_4^- reagents and samples. Method details and QA/QC considerations are provided in Section 2.4.3.

2.4.1 Terminology and Standards for Oxygen Stable Isotopic Analysis

As described in Section 1.3, stable isotopic compositions are measured and reported as relative differences of isotope ratios (in either moles or numbers of atoms) between two substances, one of which may be an international measurement standard (Equation 2.1). For oxygen:

[Eq. 2.3] $$\delta^{18}O = R(^{18}O/^{16}O)_{sample}/R(^{18}O/^{16}O)_{standard} - 1$$

[Eq. 2.4] $$\delta^{17}O = R(^{17}O/^{16}O)_{sample}/R(^{17}O/^{16}O)_{standard} - 1,$$

where the standard in both equations is Vienna Standard Mean Ocean Water (VSMOW). Values of $\delta^{18}O$ and $\delta^{17}O$ typically are reported in parts per thousand (per mil, or ‰). By international convention, the $\delta^{18}O$ scale is defined by two standards, with VSMOW at 0 and Standard Light Antarctic Precipitation (SLAP) at a value of -55.5 ‰ (Gonfiantini, 1978; Coplen, 1994).

Variations in $R(^{17}O/^{16}O)$ and $R(^{18}O/^{16}O)$ caused by most physical-chemical fractionation processes on Earth are related systematically by the relative differences in the masses of the isotopes. Such "mass-dependent" variations can vary slightly for different processes and they can be described in various ways (e.g., Thiemens, 1999; Miller, 2002; Angert et al., 2004; Assonov and Brenninkmeijer, 2005). In this report:

[Eq. 2.5] $$(1 + \delta^{17}O) = (1 + \delta^{18}O)^{\lambda},$$

with $\lambda \approx 0.525$ (Miller, 2002; Böhlke et al., 2005). Departures from mass-dependent O-isotope variation are important features of some materials, including some natural ClO_4^-. Departures from mass-dependent O-isotope variation in ClO_4^- are described in this report as deviations from the relation given in Equation 2.5:

[Eq. 2.6] $$\Delta^{17}O = [(1 + \delta^{17}O) / (1 + \delta^{18}O)^{0.525}] - 1.$$

Values of $\Delta^{17}O$ typically are reported in parts per thousand (per mil, or ‰).

Because water (H_2O) samples may not be compatible with analytical techniques used for other compounds such as ClO_4^-, Equations 2.3 and 2.4 are expanded to permit routine calibration of ClO_4^- analyses using a pair of ClO_4^- isotopic reference materials (USGS37 and USGS38) with contrasting isotopic compositions on the VSMOW-SLAP scale, a process commonly referred to as "normalization":

[Eq. 2.7] $$\delta^{18}O_{i/VSMOW} = \delta^{18}O_{37/VSMOW} + [\delta^{18}O_{i/rg} - \delta^{18}O_{37/rg}]_{meas.} \cdot [\delta^{18}O_{38/VSMOW} - \delta^{18}O_{37/VSMOW}] / [\delta^{18}O_{38/rg} - \delta^{18}O_{37/rg}]_{meas.}$$

[Eq. 2.8] $$\delta^{17}O_{i/VSMOW} = \delta^{17}O_{37/VSMOW} + [\delta^{17}O_{i/rg} - \delta^{17}O_{37/rg}]_{meas.} \cdot [\delta^{17}O_{38/VSMOW} - \delta^{17}O_{37/VSMOW}] / [\delta^{17}O_{38/rg} - \delta^{17}O_{37/rg}]_{meas.},$$

where 37 and 38 refer to the ClO_4^- reference materials USGS37 and USG38, and rg is an internal laboratory reference gas (either CO or O_2, see below) against which all samples and reference materials are analyzed in the mass spectrometer during a single batch of analyses.

The isotopic reference materials consist of reagent-grade $KClO_4$ salts that were prepared specifically for calibration of ClO_4^- isotopic analyses as part of ESTCP Project ER-200509. The $\delta^{18}O$ scale is based on CO-CF-IRMS analyses (see below) of the ClO_4^- isotopic reference materials against international H_2O, NO_3^-, and SO_4^{2-} isotopic reference materials as described by Böhlke et al. (2003), and all data are referenced to the conventional VSMOW-SLAP scale (Gonfiantini, 1978; Coplen, 1994). For $\delta^{18}O$, the secondary calibration values used to generate provisional ClO_4^- data with respect to VSMOW are -27.9 ‰ for USGS34 (KNO_3), +25.6 ‰ for IAEA-N3 (KNO_3), +57.5 ‰ for USGS35 ($NaNO_3$), and +8.6 ‰ for NBS 127 ($BaSO_4$) (Böhlke et al., 2003). The $\delta^{17}O$ scale for ClO_4^- is provisionally based on the assumption that the normal reagent $KClO_4$ reference material (USGS37) has $R(^{17}O/^{16}O)$ and $R(^{18}O/^{16}O)$ values that are related to those of VSMOW by mass-dependent processes ($\Delta^{17}O = 0$, as defined by Equation 2.6; Böhlke et al., 2005).

International efforts to reconcile $\delta^{18}O$ calibration scales for different reference materials are ongoing in the scientific community (e.g., Brand et al., 2009), as are efforts to define and calibrate mass-dependent variations in $\delta^{18}O$ and $\delta^{17}O$ for different chemical systems and processes. The current project (ESTCP ER-200509) is contributing to these efforts, while providing an interim basis for reporting and comparing O isotope data for environmental samples of ClO_4^-. Because the calibration data are provisional and could change, reported data are accompanied by descriptions of the reference materials and calibration values that were used during the analyses, and by the equations that were used to evaluate mass dependence, to permit subsequent re-evaluation and comparison with other data.

2.4.2 Analysis of $\delta^{18}O$ and $\delta^{17}O$ by Off-Line Conversion to O_2, with Dual-Inlet Isotope-Ratio Mass Spectrometry (O2-DI-IRMS)

To perform DI-IRMS on O_2 derived from ClO_4^-, aliquots of pure $CsClO_4$, $RbClO_4$, or $KClO_4$, including reagents and environmental samples derived from the sampling and purification methods described previously in Sections 2.2 and 2.3 of this document, are weighed into quartz glass tubes (mass equivalent to 2.5 µmol of ClO_4^- per tube). The tubes are evacuated and sealed with a torch and baked at 650 °C for 20 min to produce O_2 gas from the ClO_4^-. Alternatively, samples are weighed into Pyrex glass tubes (mass equivalent to 2.5 µmol of ClO_4^- per tube), which are evacuated and sealed with a torch, and baked at 600 °C for 30 min to produce O_2 gas. The tubes are broken manually in an evacuated glass tube cracker, the O_2 is expanded into a liquid N_2 cold trap for 1 min to remove traces of condensable gases (except when being tested for other decomposition products such as CO_2), then admitted to an IRMS and analyzed in dual-inlet mode against an O_2 reference gas from a tank by monitoring *m/z* 32 ($^{16}O^{16}O$), 33 ($^{17}O^{16}O$), and 34 ($^{18}O^{16}O$, plus an insignificant contribution from $^{17}O^{17}O$).

The following routine QA/QC checks for DI-IRMS analysis of O_2 are recommended:

1. Aliquots of samples and reference materials must yield constant amounts of O_2 to provide optimum conditions and minimize bias in mass spectrometry (Werner and Brand, 2001). Masses of samples and reference materials should be adjusted to yield

constant amounts of O_2 (typically within ± 10 % or less within a batch); masses should be recorded to permit subsequent yield calculations.

2. The vacuum system used to seal the tubes should be evaluated by an electronic gauge, and tubes should be sealed only if the reading is stable at a level that produces negligible O_2 blanks (this can be tested periodically by analyzing empty sealed tubes in the mass spectrometer).

3. The relative amount of O_2 released from each tube (sample yield) should be measured in the IRMS and compared to the expected amount based on the measured weight of the sample in comparison to yields from pure reagents; if a yield is substantially different, the analysis should be flagged for attention. This represents an additional QC check for sample purity, in addition to those described in Section 2.3.6.

4. The relative amounts of N_2, Ar, and CO_2 (potentially indicating air leakage or other contamination) associated with O_2 samples should be measured in the IRMS; if any are substantially higher than normal mass spectrometer blanks, the analysis should be flagged for attention (e.g., considered for rejection if other analyses of the same sample are systematically different).

5. Isotopic reference materials should be prepared and analyzed as samples (multiple aliquots) with every batch of samples being analyzed (Werner and Brand, 2001). A normal batch consists of about 10-20 samples and reference materials, all prepared identically and analyzed on the same day. For the reference materials, standard deviations of $\delta^{18}O$ analyses of multiple aliquots (typically 3-4) in a given batch generally are around ± 0.2 ‰ or better for USGS37 and ± 0.5 ‰ or better for USGS38; if substantially larger, then the analyses should be flagged for attention (e.g., considered for rejection if other analyses of the same samples are systematically different).

6. With few exceptions, such as when sample amounts are limited, samples should be analyzed at least twice in different batches on different days, to minimize bias related to daily calibrations. The stated uncertainties of sample analyses are based on these replicates.

2.4.3 Analysis of $\delta^{18}O$ by On-Line Conversion to CO, with Continuous-Flow Isotope-Ratio Mass Spectrometry (CO-CF-IRMS)

To perform CF-IRMS on CO derived from ClO_4^-, aliquots of pure $CsClO_4$, $RbClO_4$, or $KClO_4$, including reagents and environmental samples derived from the sampling and purification methods detailed previously in Sections 2.2 and 2.3 of this document, are weighed into silver foil cups (mass equivalent to 2 µmol of ClO_4^- per cup). The loaded cups are dropped automatically from a He-flushed carousel into a graphite crucible in a glassy carbon reactor at a nominal (gauge) temperature of 1325 °C to produce CO gas from the ClO_4^-. The CO is transferred in He carrier gas through a molecular-sieve gas chromatograph to an IRMS and analyzed in continuous-flow mode by monitoring peaks at *m/z* 28 ($^{12}C^{16}O$) and 30 ($^{12}C^{18}O$, plus an insignificant contribution from $^{13}C^{17}O$).

The following routine QA/QC checks for CF-IRMS of CO are recommended:

1. Aliquots of samples and reference materials should yield constant amounts of CO to provide optimum conditions and minimize bias in mass spectrometry. Masses of samples and reference materials should be adjusted to yield constant amounts of CO (typically within ± 5 % or less within a batch); masses should be recorded to permit subsequent yield calculations.

2. The relative amount of CO released from each aliquot (sample yield) should be measured in the mass spectrometer and compared to the expected amount based on the measured mass of the sample in comparison to yields from pure reagents; if a yield is substantially different, the analysis should be flagged for attention.

3. The relative amount of N_2 (potentially indicating air leakage or other contamination, such as NO_3^-) in each sample should be measured in the IRMS by monitoring *m/z* 28

throughout the continuous-flow run from the GC (the $^{14}N^{14}N$ peak precedes the $^{12}C^{16}O$ peak). Typically, the area of the $^{14}N^{14}N$ peak is negligible; if not, the analysis should be flagged for attention.

4. Isotopic reference materials should be prepared and analyzed as samples (multiple aliquots) with every batch of samples being analyzed. A typical normal batch consists of about 30-50 samples and reference materials, all analyzed in the same run within a 24-hour period. For the reference materials, standard deviations of $\delta^{18}O$ analyses of multiple aliquots (typically 4-8) in a given batch generally are around ± 0.2 ‰ or better for USGS37 and ± 0.2 ‰ or better for USGS38; if substantially larger, the analysis should be flagged for attention.

5. With few exceptions, such as when samples are limited), samples should be analyzed at least twice in different batches on different days, to minimize bias related to daily calibrations. The stated uncertainties of sample analyses are based on these replicates.

2.5 Analysis of Chlorine Isotopes in Perchlorate by Isotope-Ratio Mass Spectrometry

The analysis of Cl stable isotopes is conducted on the Cl^- produced by decomposition of alkali ClO_4^- salts as described in Section 2.4 for production of O_2. The Cl^- derived from ClO_4^- initially is converted to methyl chloride (CH_3Cl) gas by reaction of AgCl with CH_3I (Eggencamp, 1994; Holt et al., 1997), which is then analyzed by IRMS according to the procedures described in this section. The methods and calibrations of Cl isotopic analyses from ClO_4^- have been summarized previously in several papers and book chapters as described in Section 2.1.

2.5.1 Terminology and Standards for Chlorine Stable Isotopic Analysis

As described in Section 1.3, stable isotopic compositions are measured and reported as relative differences of isotope ratios (in either moles or numbers of atoms) between two substances, one of which may be an international measurement standard (Equation 2.1). For chlorine:

[Eq. 2.9] $$\delta^{37}Cl = R(^{37}Cl/^{35}Cl)_{sample} / R(^{37}Cl/^{35}Cl)_{standard} - 1$$

where the international measurement standard is Standard Mean Ocean Chloride (SMOC). Values of δ^{37}Cl typically are reported in parts per thousand (per mil, or ‰). The most widely-used Cl isotope reference material is chloride prepared from seawater which has uniform δ^{37}Cl to within ± 0.08 ‰ (Godon et al., 2004).

Routine calibration of ClO_4^- isotopic analyses can be done by using a pair of ClO_4^- isotopic reference materials (USGS37 and USGS38) with contrasting isotopic compositions, a process commonly referred to as "normalization":

[Eq. 2.10] $$\delta^{37}Cl_{i/SMOC} = \delta^{37}Cl_{37/SMOC} + [\delta^{37}Cl_{i/rg} - \delta^{37}Cl_{37/rg}]_{meas.} \cdot [\delta^{37}Cl_{38/SMOC} - \delta^{37}Cl_{37/SMOC}] / [\delta^{37}Cl_{38/rg} - \delta^{37}Cl_{37/rg}]_{meas.}$$

where 37 and 38 refer to the perchlorate isotopic reference materials USGS37 and USG38, and rg is an internal laboratory reference gas (CH_3Cl) against which all samples and reference materials are analyzed in the mass spectrometer during a single batch of analyses.

Isotopic reference materials consist of reagent-grade $KClO_4$ salts that were prepared specifically for calibration of ClO_4^- isotopic analyses as described previously in Section 2.4.1. The δ^{37}Cl scale is based on isotopic analyses of the USGS perchlorate isotopic reference materials against SMOC. As noted for O isotopes in ClO_4^-, the current ClO_4^- isotope project (ESTCP ER-200509) is providing an interim basis for reporting and comparing Cl isotope data for environmental samples of ClO_4^-. Because the calibration data are provisional and could change, reported data are accompanied by statements describing the normalization equations and values that were used during the analyses to permit subsequent re-evaluation.

2.5.2 Analysis of δ^{37}Cl by Off-Line Conversion to Methyl Chloride, with Dual-Inlet Isotope-Ratio Mass Spectrometry (CH_3Cl-DI-IRMS)

Chlorine isotopic analyses are performed on samples of alkali halide (CsCl, RbCl, or KCl) residues from decomposition of ClO_4^- salts as described above for preparation of O_2 for isotopic analysis (Section 2.4.2). Alkali halide residue in a decomposition tube is dissolved

using 10 mL of warm 18.2 MΩ deionized water. The dissolved alkali halide residue is transferred into a 50-mL polypropylene conical tube. Sodium phosphate/citric acid buffer (0.004 M phosphate, 0.098 M citric acid) and potassium nitrate (0.4 M KNO_3) are added to optimize crystallization of AgCl in the subsequent step. This solution is then heated to 80 °C and an excess of silver nitrate ($AgNO_3$) is added as described in Eggenkamp (1994). Silver chloride (AgCl) precipitates are then allowed to ripen in the dark for ~ 24 hr. The AgCl solids are then centrifuged, the supernatant is removed, and dilute 0.03 M nitric acid (HNO_3) is used to rinse the solids three times. Solids are then transferred into a Pyrex combustion tube (20 cm x 9 mm) and dried in a darkened vacuum oven at 80 °C. After the sample is dry, the combustion tube is evacuated and methyl iodide (CH_3I) is cryogenically transferred into the tube which is then sealed and baked for 2 h at 300 °C as described in Holt et al. (1997). The resulting CH_3Cl is purified using gas chromatography, cryo-concentrated, and then admitted to an IRMS and analyzed in dual-inlet mode by monitoring peaks at *m/z* 52 ($^{12}C^{1}H_3{}^{37}Cl$) and 50 ($^{12}C^{1}H_3{}^{35}Cl$). Samples smaller than 5 μmol of Cl (0.5 mg ClO_4^-) can be analyzed by CF-IRMS, as described in Section 2.5.3.

The following routine QA/QC checks for DI-IRMS analysis of Cl are recommended:

1. Preparation of every batch of 10-15 samples should include the concurrent preparation of two different USGS perchlorate isotopic reference materials (USGS37 and USGS38) as described previously. Seawater chloride samples should also be analyzed with each batch to monitor instrument performance and stability.

2. Aliquots of samples and reference materials must yield constant amounts of Cl to provide optimum conditions and minimize bias in mass spectrometry. Masses of samples and reference materials should be adjusted to yield constant amounts of Cl (typically within ± 5 % or less within a batch); masses should be recorded to permit subsequent yield calculations.

3. The vacuum system used to seal the tubes should be evaluated by an electronic gauge, and tubes sealed only if the reading is stable at a level that produces negligible CH_3Cl blanks (tested periodically by analyzing empty sealed tubes in the mass spectrometer).

4. The relative amount of CH_3Cl released from each tube (sample yield) should be measured in the IRMS and compared to the expected amount based on the measured mass of the sample, in comparison to yields from pure reagents; if a yield is substantially different, the analysis should be flagged for attention.

5. The relative amounts of N_2, Ar, and CO_2 (potentially indicating air leakage or other contamination) in each CH_3Cl aliquot are measured in the IRMS; if any of these are substantially higher than normal mass spectrometer blanks, the analysis should be flagged for attention.

6. Isotopic reference materials should be prepared and analyzed as samples (multiple aliquots) with every batch of samples being analyzed. A normal batch consists of about 10-20 samples and reference materials, all analyzed on the same day. For the reference materials, standard deviations of δ^{37}Cl analyses of multiple aliquots generally are around ± 0.2 ‰ or better for USGS37 and ± 0.3 ‰ or better for USGS38; if substantially larger, the analysis should be flagged for attention.

7. With few exceptions, such as when samples amounts are limited, samples should be analyzed at least twice in different batches on different days, to minimize bias related to daily calibrations. The stated uncertainties of sample analyses are based on these replicates.

2.5.3 Analysis of δ^{37}Cl by On-Line Separation of Methyl Chloride, with Continuous-Flow Isotope-Ratio Mass Spectrometry (CH_3Cl-CF-IRMS)

Small samples (< 5 μmol of Cl in CH_3Cl) can be analyzed for Cl isotopic composition by CF-IRMS rather than DI-IRMS (Section 2.5.2). The same general sample preparation techniques are used as described in Section 2.5.2 until the final steps. The reacted

CH_3Cl/CH_3I mixture is transferred in a He carrier-gas through a molecular-sieve gas chromatograph to separate CH_3Cl from CH_3I, then the He carrier-gas is admitted to an IRMS and the Cl isotope ratio analyzed in continuous-flow mode by monitoring peaks at *m/z* 52 ($^{12}C^1H_3{}^{37}Cl$) and 50 ($^{12}C^1H_3{}^{35}Cl$).

The following routine QA/QC checks are recommended for Cl isotopic analysis by CH_3Cl-CF-IRMS:

1. Preparation of every batch of 10-15 samples should include the concurrent preparation of two different USGS perchlorate isotopic reference materials as described previously. Seawater chloride samples should also be analyzed with each batch to monitor instrument performance and stability.

2. Aliquots of samples and reference materials must yield constant amounts of Cl to provide optimum conditions and minimize bias in mass spectrometry. Masses of samples and reference materials should be adjusted to yield constant amounts of Cl (typically within ± 5 % or less within a batch); masses should be recorded to permit subsequent yield calculations.

3. The relative amounts of N_2, Ar, and CO_2 (potentially indicating air leakage or other contamination) in each CH_3Cl aliquot are measured in the IRMS; if any are substantially higher than normal mass spectrometer blanks, the analysis should be flagged for attention.

4. Isotopic reference materials should be prepared and analyzed as samples (multiple aliquots) with every batch of samples being analyzed. A normal batch consists of about 10-20 samples and reference materials, all analyzed on the same day. For the reference materials, standard deviations of $\delta^{37}Cl$ analyses of multiple aliquots generally are around ± 0.2 ‰ or better for USGS37 and ± 0.5 ‰ or better for USGS38; if substantially larger, the analysis should be flagged for attention.

5. With few exceptions, such as when samples amounts are limited), samples should be analyzed at least twice in different batches on different days, to minimize bias related to

daily calibrations. The stated uncertainties of sample analyses are based on these replicates.

2.6 Analysis of ^{36}Cl from Perchlorate

Chlorine-36 (^{36}Cl) is a long-lived radioactive isotope of Cl with a half-life of ~ 301,000 yr. The abundance of ^{36}Cl in a sample traditionally is expressed as ^{36}Cl/Cl, which is equivalent to the atom fraction or mole fraction of ^{36}Cl, $x(^{36}\mathrm{Cl})$, or $N(^{36}\mathrm{Cl})/N(\Sigma\mathrm{Cl})$. Meteoric water has an average natural ^{36}Cl/Cl value of approximately 700×10^{-15} (Bentley et al., 1986; Phillips, 2000; Davis et al., 2003). ^{36}Cl is formed primarily in the stratosphere through the cosmic ray spallation of ^{40}Ar (Lehmann et al., 1993). This radioactive isotope is of interest for forensic analysis of ClO_4^- because recent data indicate that it is significantly enriched in natural indigenous ClO_4^- samples collected from the southwestern U.S. (^{36}Cl/Cl values ranging from 3130×10^{-15} to $28{,}800 \times 10^{-15}$) compared to either synthetic samples (^{36}Cl/Cl values ranging from 0×10^{-15} to 40×10^{-15}) or natural Chilean samples (^{36}Cl/Cl values ranging from 22×10^{-15} to 590×10^{-15}) (Sturchio et al., 2009, 2011). Additional details on ^{36}Cl are provided in Section 3.3. However, the current data indicate that analysis of ^{36}Cl can provide important evidence concerning the origin of ClO_4^- in environmental samples. Therefore, the basic method for analysis is provided herein.

Analysis of ^{36}Cl in ClO_4^- is performed by accelerator mass spectrometry (AMS) using Cl^- derived from ClO_4^-. There are a limited number of AMS facilities in the U.S., and the ^{36}Cl analyses on ClO_4^- reported to date have been performed at the Purdue Rare Isotope Measurement Laboratory (PRIME) at Purdue University (www.physics.purdue.edu/ primelab). The basic procedure used to produce Cl^- for AMS is as described in Section 2.5.2 of this document to the point of AgCl precipitation, washing, and drying of crystals (i.e., prior to the reaction with CH_3I). Generally, a portion of the sample prepared to this step for Cl stable isotopic analysis is saved for ^{36}Cl analysis. The AgCl is subsequently re-dissolved and the Cl^- is purified twice by anion chromatography (using a method developed by the PRIME Lab at Purdue University; http://www.physics.purdue.edu/primelab/ AMSQAQC/chemProc004.pdf) to ensure removal of trace amounts of S that might cause isobaric interference at mass 36. Purified Cl^- is then re-precipitated as AgCl for AMS

measurement. Analysis of seawater Cl^- provides a reference datum of $^{36}Cl/Cl = 0.5 \times 10^-$ (Argento et al., 2010).

2.7 Summary of Sampling, Purification and Analysis of Chlorine and Oxygen Isotopes in Perchlorate

A summary of the general procedures involved in the collection, purification, and analysis of ClO_4^- samples for Cl and O isotopes is provided in Figure 2.10. The procedures, which are provided in detail in the previous sections, are summarized as follows:

1. ClO_4^- (10 mg) is collected directly from groundwater using IX resin columns or collected from mineral deposits and(or) soils by extraction of solids with ClO_4^--free water and collection of dissolved ClO_4^- from the extract using IX resin columns. Columns can be preserved with 0.05 N HCl.

2. The ClO_4^- is then eluted from the IX column after an initial wash with 4 M HCl to remove impurities using a solution with $FeCl_4^-$. Fractions are collected during the elution phase to minimize total volume of the ClO_4^- bearing eluent.

3. The ClO_4^- in the eluent subsequently is purified by a series of steps that include Fe removal by either cation exchange or precipitation, and then the ClO_4^- is concentrated and unwanted salts are removed by precipitation and filtration. The dissolved ClO_4^- is then crystallized as cesium perchlorate ($CsClO_4$), potassium perchlorate ($KClO_4$), or rubidium perchlorate ($RbClO_4$).

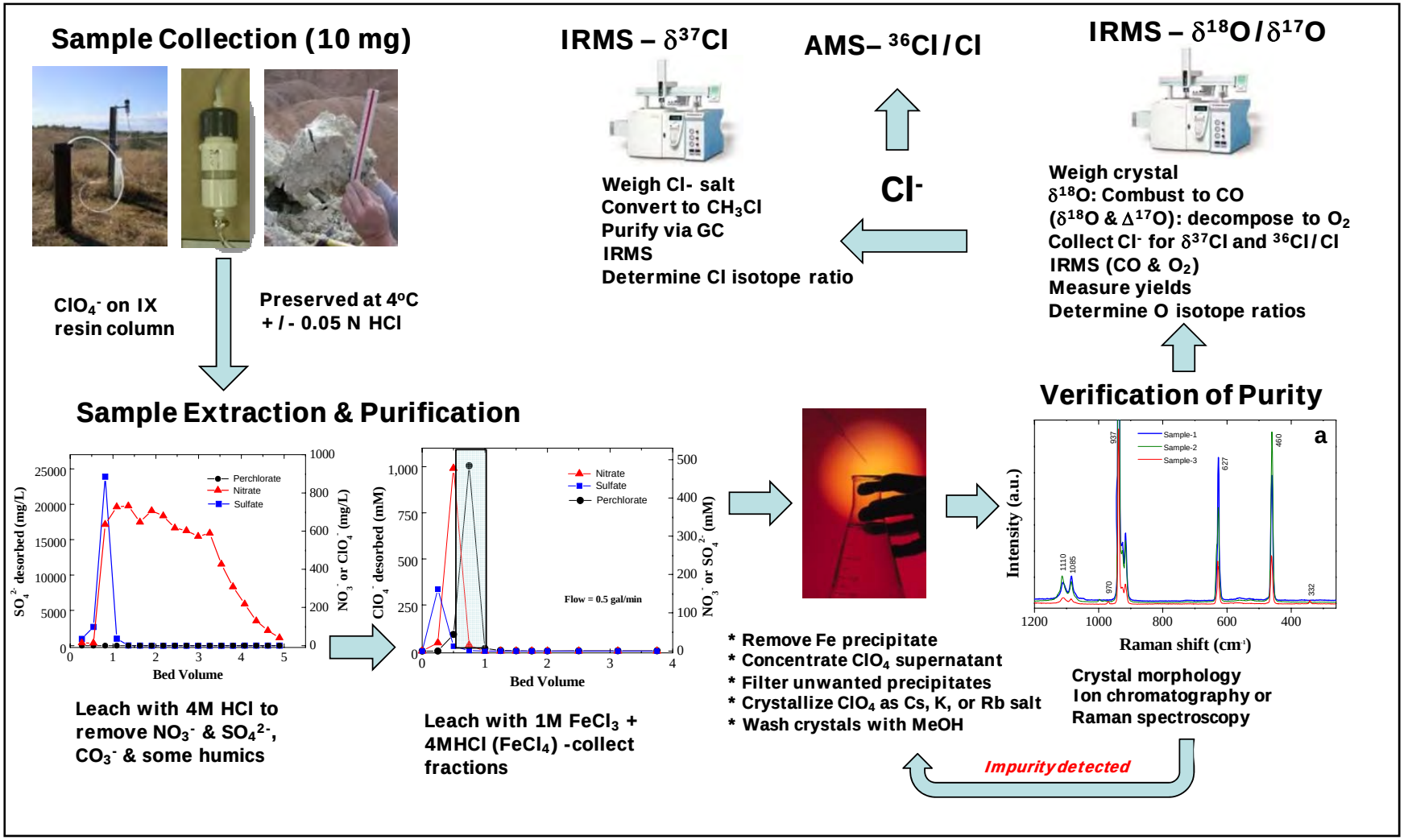
4. The crystals are collected via filtration or evaporation and washed with methanol, after which the purity is determined by crystal morphology, Raman spectroscopy, and(or) ion chromatography. If oxygen-containing impurities are detected at concentrations greater than 1 % for the mole fraction of O in the ClO_4^- sample, the sample is re-purified.

5. After crystals are determined to be pure, $\delta^{18}O$ is measured by on-line conversion to CO with CF-IRMS and $\delta^{18}O$ and $\Delta^{17}O$ are measured by off-line conversion to O_2 with DI-IRMS.

6. Aliquots of alkali halide (CsCl, RbCl, or KCl) remaining after the decomposition of ClO_4^- salts for O isotopic analyses (Step 5) are collected, converted to CH_3Cl, and then analyzed for $\delta^{37}Cl$ using either DI-IRMS or CF-IRMS depending on sample size.

7. Additional aliquots of alkali halide from Step 5 are converted to AgCl and analyzed for $^{36}Cl/Cl$ by AMS.

Figure 2.10. Overview of the procedures involved in the collection, purification, and analysis of ClO_4^- samples for Cl and O isotopic composition.



2.8 Supporting Information for Perchlorate Forensic Studies

There are a variety of analytical techniques that can potentially provide important supporting information concerning the origin of ClO_4^- in groundwater (e.g., Clark and Fritz, 1997; Cook and Herczeg, 2000). Examples of relevant methods and basic sample collection procedures are provided in Table 2.1. Numerous laboratories conduct various combinations of these different types of analyses, including facilities at USGS, national laboratories, and universities. The supporting methods are described briefly in the sections below.

2.8.1 Field Parameters

Typical geochemical parameters should be collected at each well during ClO_4^- sampling using a field meter (e.g., YSI 6000 XL multi-parameter meter; YSI Inc., Yellow Springs, OH). The parameters, which provide a basic geochemical baseline for each well, include temperature, dissolved oxygen, oxidation-reduction potential, conductivity, and pH. The stabilization of these parameters with time is used in low-flow sampling applications to determine when to collect field samples, as described in Section 2.2.2 of this document. In addition, these parameters can be useful for assessing relations between water masses and geochemical conditions that could affect the stability of ClO_4^- through biodegradation.

2.8.2 Groundwater-Age Dating

The age of groundwater (time since infiltration or recharge) is an important forensic tool for ClO_4^- that may be either natural or anthropogenic in origin, particularly given that much of the known synthetic ClO_4^- contamination in the U.S. occurred after the 1940s. Measurable groundwater ages in aquifers commonly range from years to millennia and therefore can be used to relate ClO_4^- occurrences to land-use history, as was recently done in Long Island, New York, in support of isotopic data showing that Chilean nitrate fertilizers account for some of the groundwater ClO_4^- in this region (see Section 4.0 and Böhlke et al., 2009). Groundwater ages between about 0 and 60 yr can be determined by analyses of atmospheric environmental tracers including tritium (^3H), sulfur hexafluoride (SF_6), and chlorofluorocarbons (CFCs), all of which have been incorporated in groundwater in varying concentrations since the middle of the 20th century (similar to synthetic ClO_4^-). Analyses of ^3He, the decay product of ^3H, provide additional estimates of groundwater age. Analysis of dissolved neon (Ne) also is conducted during tritium-helium age dating to evaluate degassing or the presence of excess air in samples. Groundwater ages on the order of 10^3 to 10^4 yr can be estimated from concentrations of ^{14}C, as was done in the southwestern U.S. to document the occurrence of natural (pre-anthropogenic) ClO_4^-

(Plummer et al., 2006; Jackson et al., 2010). Descriptions of collection and interpretation of groundwater-age data are described in several publications (Cook and Herczeg, 2000; Busenberg and Plummer, 1992, 2000), with additional details in the following sources and references therein (Thatcher et al., 1976; USGS, 2011a).

2.8.3 Stable Hydrogen and Oxygen Isotopes in Water

The stable H and O isotopic composition of H_2O is used commonly to distinguish sources of water, effects of evaporation, and in some cases relative ages of groundwater (Coplen et al., 2000; Clark and Fritz, 1997), all of which may be useful in some situations for distinguishing sources of ClO_4^-. Analyses of H and O isotopes in water can be performed by equilibration with H_2 and CO_2, respectively, for mass spectrometry (Coplen et al., 1991; Révész and Coplen, 2011; USGS, 2011b).

2.8.4 Stable Nitrogen and Oxygen Isotopes in Nitrate

Nitrate (NO_3^-) commonly occurs with ClO_4^- because both are produced naturally in the atmosphere, both may be introduced by agricultural practices, and both have similar transport properties and similar susceptibility to biodegradation. Therefore, stable isotopic and other evidence for the origin and fate of NO_3^- (Heaton, 1986; Kendall and Aravena, 2000; Böhlke, 2002; Böhlke et al., 1997; Michalski et al., 2004; McMahon and Böhlke, 2006) can provide important information concerning the origin and behavior of coexisting ClO_4^- in some situations (e.g., Plummer et al., 2006; Jackson et al., 2010). The stable isotopes of N and O in NO_3^- can be analyzed by various methods including bacterial conversion to N_2O and continuous-flow mass spectrometry (Sigman et al., 2001; Casciotti et al., 2002; Coplen et al., 2004; Révész and Coplen, 2011; USGS, 2011b).

2.8.5 Stable Sulfur and Oxygen Isotopes in Sulfate

Sulfate (SO_4^{2-}) is another oxyanion that may be associated with ClO_4^- as a result of atmospheric deposition or anthropogenic applications, and it may indicate changes in redox conditions that affect ClO_4^- transport. Stable isotopic analyses of SO_4^{2-} can be useful in evaluating sources and fate of SO_4^{2-} (Krouse and Grinenko, 1991; Krouse and Mayer, 2000), which may provide information about ClO_4^- distribution in aquifers. The stable isotopes of sulfur and oxygen in SO_4^{2-} can be analyzed by high-temperature conversion of $BaSO_4$ to SO_2 and CO, respectively, for mass spectrometry (Carmody et al., 1998; Révész and Coplen, 2011; USGS, 2011b).

2.8.6 Dissolved Gas Concentrations

Concentrations of dissolved gases provide important information about groundwater recharge temperatures (Ar, N_2, Ne Kr, Xe) and subsurface redox reactions (O_2, CH_4, N_2). Recharge temperatures are important for the estimation of groundwater ages from atmospheric environmental tracers (Section 2.8.2) and they may be useful for distinguishing water masses from different sources and ages (Cook and Herczeg, 2000). In addition, past and current redox conditions are critical for understanding the potential for ClO_4^- biodegradation in aquifers (e.g., Coates and Achenbach, 2004). Dissolved N_2 concentrations can be used to assess whether a sample has experienced denitrification (e.g., Böhlke et al., 2002), which typically precedes ClO_4^- reduction as conditions become reducing. Major dissolved gases can be analyzed by gas chromatography on equilibrated headspace (USGS, 2011a). Neon analyses typically are done as part of the ^3H-^3He groundwater dating method (USGS, 2011a).

2.8.7 Trace Element Concentrations

Trace element analysis may be helpful, for example where fireworks are a potential source of ClO_4^-. Elements commonly associated with fireworks include aluminum (Al), antimony (Sb), barium (Ba), calcium (Ca), magnesium (Mg), potassium (K), sodium (Na), and strontium (Sr), (Conklin, 1985) and correlations between ClO_4^- and these elements are possible if fireworks are a source (e.g., Böhlke et al., 2009). A common method for analysis of trace elements is Inductively Coupled Plasma Mass Spectrometry (ICP-MS) according to modified EPA Method 200.8 (USEPA, 1994).

2.8.8 Anion Concentrations

Typical groundwater anions, including NO_3^-, Cl^-, Br^-, and SO_4^{2-} can be measured, in addition to ClO_4^-, to provide geochemical background information for each well. It may also be useful to measure iodate (IO_3^-), which can form atmospherically and has been observed to co-occur with natural ClO_4^- in groundwater beneath the Southern High Plains (SHP) of West Texas and New Mexico (Dasgupta et al., 2005). Samples should be filtered (preferably with pore size 0.2 µm or smaller) in the field to minimize the possibility of biodegradation of some anions during storage. The anions, except IO_3^-, can be analyzed by ion chromatography according to EPA Method 300.0. IO_3^- can be measured using high performance liquid chromatography with UV detection (HPLC-UV), as described in Dasgupta et al. (2005) or by liquid chromatography−tandem mass spectrometry (LC−MS/MS) (Snyder et al., 2005).

Table 2.1 Examples of Supporting Analytical Methods and Sampling Requirements

Field Measurement		**Equipment**			
Temperature		Field meter			
Specific conductivity		Field meter			
pH		Field meter			
Dissolved O_2		Field meter			
Reduction potential		Field meter			
Sample	**#**	**Container**	**Filter**	**Treatment**	**Analytical Lab**
Water H and O isotopes*	2	60-mL glass, Polyseal cap	no	small headspace, ship cool	USGS
Tritium* (groundwater dating)	2	500-mL glass, Polyseal cap	no	small headspace, ship cool	USGS
Major gases*	3	serum bottle, pre-weighed butyl stopper, crimper-top	no	no bubbles, 1 KOH pellet, cap underwater, 4 °C	USGS
He and Ne isotopes* (groundwater dating)	3	Cu tube, crimped	no	no bubbles, backpressure, crimp while flowing	USGS
CFC* Groundwater dating)	5	CFC bottle, Al-lined cap	no	no bubbles, cap underwater, tape on cap, 4 °C	USGS
SF_6* (groundwater dating)	2	2.5-L glass, Polyseal cap	no	no bubbles	USGS
Trace elements	2	125-mL HDPE, acid-rinsed	0.2 µm	In-line filter, 1 mL clean HNO_3	USGS
Anions	2	50-mL sterile poly tube	0.2 µm	Sterile syringe filter – aerobic headspace - 4 °C	Shaw Environmental
NO_3^- N and O isotopes	1	1-L HDPE, Polyseal cap	0.2 µm	KOH pellets (pH > 11)	USGS
SO_4^{2-} S and O isotopes (>20 mg/L)*	1	- L HDPE, Polyseal cap	0.2 µm	None – ship cool	USGS
SO_4^{2-} S and O isotopes (<20 mg/L)*	1	resin cartridge, HCl, $BaCl_2$, bucket	in cartridge	None – ship cool	USGS
Perchlorate (ClO_4^-)	1	50-mL sterile poly tube	0.2 µm	Sterile syringe filter – aerobic headspace - 4 °C	Shaw Environmental
Iodate (IO_3^-)	1	50-mL sterile poly tube	0.2 µm	Sterile syringe filter – aerobic headspace - 4 °C	Texas Tech University

Methods and laboratories commonly used for field studies conducted for ESTCP-ER200509; other procedures and laboratories are also available.
* For additional details, see the following websites: http://isotopes.usgs.gov/; http://water.usgs.gov/lab/cfc/.

3.0 RESULTS AND INTERPRETATIONS

This section of the document (1) summarizes the stable Cl and O isotope characteristics of synthetic and natural ClO_4^- in "source" samples (e.g., Chilean fertilizer, commercial reagents, fireworks, flares, etc.); (2) describes potential isotopic effects of post depositional processes such as biodegradation and O exchange of ClO_4^-, and (3) provides examples of recent forensic evaluations of ClO_4^- in groundwater at different sites. Section 4.0 provides a recent case study of Cl and O isotopic analyses conducted on Long Island, New York, to distinguish ClO_4^- sources.

3.1 Stable Isotopes of Chlorine and Oxygen in Synthetic Perchlorate

Synthetic ClO_4^- is synthesized electrochemically using NaCl and H_2O (Schumacher, 1960). Samples from a variety of different synthetic sources, including laboratory reagents, commercial manufacturers, and ClO_4^- derived from road flares, fireworks, Pyrodex gunpowder, and chlorate herbicides, have been analyzed for Cl and O stable isotopes. Additional details on these samples are provided in Bao and Gu (2004), Böhlke et al. (2005), and Sturchio et al. (2006, 2011). Some data are unpublished results from ESTCP Project ER-200509. Data for samples of synthetic ClO_4^- in which both $\delta^{18}O$ and $\delta^{37}Cl$ values were measured are shown in Figure 3.1, and specific samples grouped by manufacturer (source) are shown in Figure 3.2. In addition, the complete published dataset is provided in Appendix A.

The $\delta^{37}Cl$ values of all synthetic ClO_4^- samples presented in Figure 3.1 group within a range from -3.1 ‰ to + 2.3 ‰ and have a mean value of ~ + 0.6 ‰. This value is near that reported for common industrial sources of NaCl, such as halite from Phanerozoic bedded evaporates, which has reported $\delta^{37}Cl$ values of 0.0 ± 0.9 ‰ (Eastoe et al., 2007). The electrochemical synthesis of ClO_4^- is nearly stoichiometric for Cl^- (i.e., nearly all of the added Cl^- is converted to ClO_4^-), so it is not surprising that the Cl isotope values in the resulting ClO_4^- are similar to those in the starting NaCl. The current $\delta^{18}O$ values of synthetic ClO_4^- vary over a wider range than for $\delta^{37}Cl$, from -24.8 ‰ to -12.5 ‰ (Figure 3.1). It has been hypothesized that the $\delta^{18}O$ values of the synthetic ClO_4^- samples reflect the $\delta^{18}O$ in the H_2O used for production, and that some O isotopic fractionation occurs during ClO_4^- synthesis (Sturchio et al., 2006). In one set of samples in which $\delta^{18}O$ was

measured in both the produced ClO_4^- and the local meteoric H_2O used in the synthesis, the observed difference was ~ 7 ‰ (Sturchio et al., 2006). In contrast to $\delta^{18}O$, $\Delta^{17}O$ values of all synthetic ClO_4^- samples analyzed to date are 0.0 ± 0.1 ‰ (when calibrated by assuming USGS37 reference material has $\Delta^{17}O$ = 0), indicating that there is negligible mass-independent isotopic fractionation of O during ClO_4^- synthesis (Sturchio et al., 2006, 2011).

When multiple samples of ClO_4^- from individual manufacturers have been analyzed, the $\delta^{18}O$ and $\delta^{37}Cl$ values group closely together (Figure 3.2). For example, the $\delta^{18}O$ values of three salts produced by Manufacturer A ($KClO_4^-$, $NaClO_4^-$, and $NH_4ClO_4^-$, respectively) ranged from -21.3 to -22.3 ‰ (-21.7 ± 0.5 ‰) and the $\delta^{37}Cl$ value for all three samples was +0.4 ‰ (from Sturchio et al., 2006). The $\delta^{18}O$ for ClO_4^- salts from Manufacturer B ranged from -15.6 to -16.3 ‰ (-16.1 ± 0.5 ‰) and the $\delta^{37}Cl$ values averaged +0.8 ± 0.6 ‰. In this specific instance, the $\delta^{18}O$ values of ClO_4^- produced by the two manufacturers would permit the two sources to be distinguished (i.e., the values between manufacturers are statistically different). However, use of stable isotopes to distinguish synthetic sources of ClO_4^- in the field may be limited by uncertainties about undocumented sources. Substantial isotopic differences among synthetic ClO_4^- sources mainly occur in $\delta^{18}O$ and, in contrast to the specific example provided in Fig 3.2, there is substantial overlap in the $\delta^{18}O$ values of different products tested to date, as is apparent from the data in Figure 3.1. In addition, differences in $\delta^{18}O$ values for ClO_4^- produced by a single manufacturer in different batches and(or) over long time periods have not been studied.

In addition to electrochemical synthesis, ClO_4^- is known to be produced over time (to concentrations of the order of milligrams per liter) in hypochlorite solutions (e.g., commercial bleach) by disproportionation reactions (Kang et al., 2006; Trumpolt et al., 2005). Only two samples of ClO_4^- derived from bleach have thus far been analyzed, and both samples had unusually low values of $\delta^{18}O$ (< -50 ‰) and high values of $\delta^{37}Cl$ (> +9 ‰) (ESTCP Project ER-200509, unpublished data). If similar values are found as more samples are analyzed, $\delta^{18}O$ and $\delta^{37}Cl$ values may be useful for distinguishing ClO_4^- derived from bleach from that produced by electrochemical synthesis.

Figure 3.1. Values of δ^{37}Cl versus δ^{18}O for samples of synthetic ClO_4^- from different sources. Analytical uncertainty is ~ ±0.3 ‰. Dashed line is δ^{37}Cl reference value of 0 for SMOC.

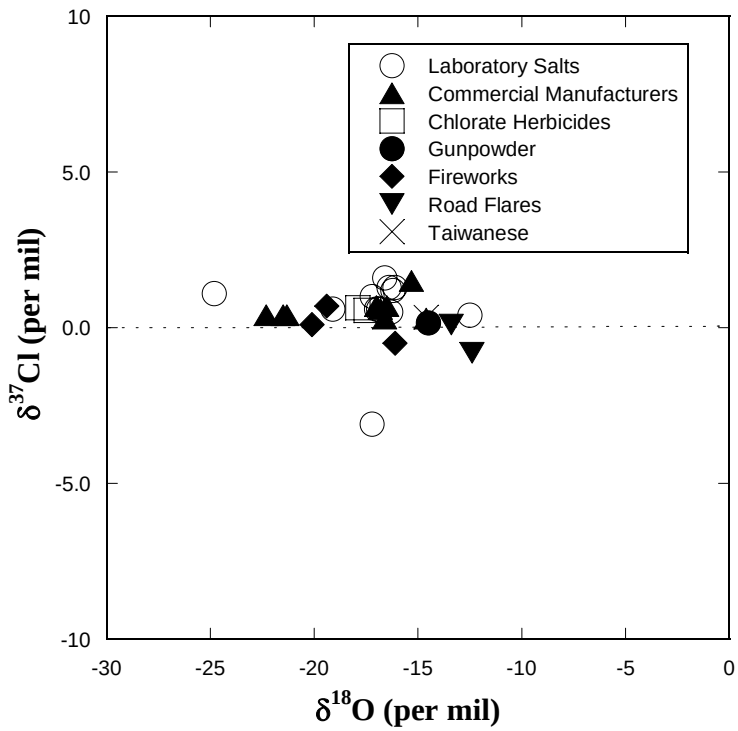
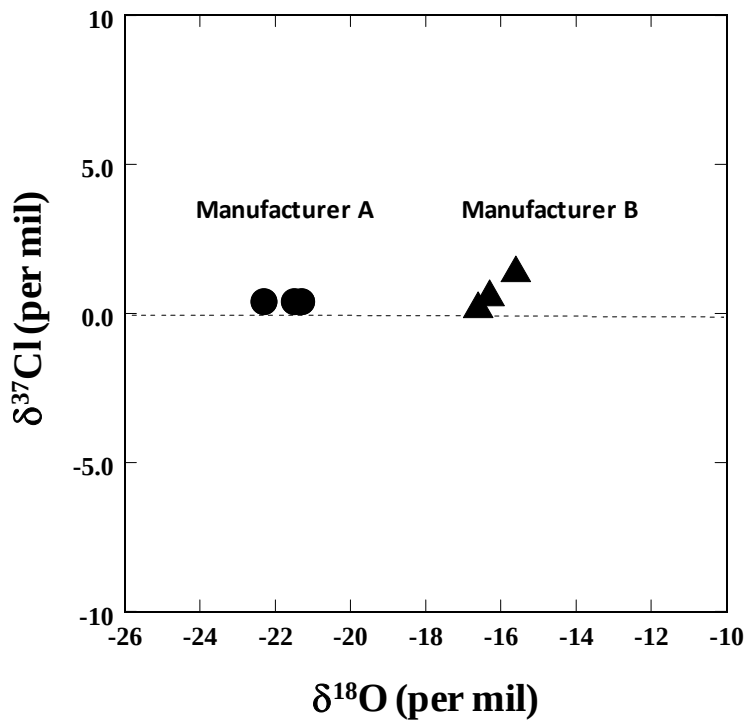


Figure 3.2. Values of δ^{37}Cl versus δ^{18}O for samples of synthetic ClO_4^- from two different manufacturers. Analytical uncertainty is ~±0.3 ‰. Dashed line is δ^{37}Cl reference value of 0 for SMOC.



3.2 Stable Isotopes of Chlorine and Oxygen in Natural Perchlorate

3.2.1 Chilean Nitrate Deposits and Imported Fertilizer

As described in Section 1.1.2, the most well-known source of natural ClO_4^- is nitrate deposits from the Atacama Desert of Chile (Schilt, 1979; Ericksen, 1981, 1983; Dasgupta et al., 2005). These nitrate deposits, which are also called "Chilean caliche", were widely imported into the United States during the 20th century as a source of inorganic nitrogen fertilizer. It is estimated that ClO_4^- derived from Chilean fertilizers represents an equivalent source to that of synthetic products in terms of ClO_4^- exposure risk through incorporation of ClO_4^- into the food chain (Dasgupta et al., 2005).

Values of $\delta^{18}O$ and $\Delta^{17}O$ in ClO_4^- from the Atacama Desert were first reported by Bao and Gu (2004). The $\delta^{18}O$ values in the Chilean samples that they analyzed (three caliche samples and one sample of imported fertilizer) ranged from -24.8 ‰ to -4.5 ‰ and $\Delta^{17}O$ values ranged from +4.2 ‰ to +9.6 ‰, with an average value of +8.0 ‰. The original observation that Chilean ClO_4^- has substantial^{17}O excess (i.e., ^{17}O higher than that expected from mass-dependent isotopic fractionation, which should yield $\Delta^{17}O$ near 0), was subsequently confirmed by analysis of a large number of additional ClO_4^- samples from Atacama Desert caliche deposits, groundwater, and imported Chilean fertilizers from this region (Böhlke et al. 2005; Sturchio et al., 2006, 2011; Jackson et al., 2010) (Figure 3.3). These studies also documented that the $\delta^{37}Cl$ values of the Chilean materials are significantly lower than those of synthetic ClO_4^-, ranging from -14.5 ‰ to -11.8 ‰.

The high values of $\Delta^{17}O$ in the Chilean samples are interpreted to indicate an atmospheric origin of this natural ClO_4^- by photochemical reactions between volatile Cl species and ozone (O_3), the latter of which is also known to be characterized by large positive $\Delta^{17}O$ values (Johnson et al., 2000; Bao and Gu, 2004). The formation of ClO_4^- with O_3 as a reactant was also recently confirmed in laboratory studies (Kang et al., 2008; Rao et al., 2010), and subsequent isotopic analysis of the O_3-generated ClO_4^- revealed a large positive $\Delta^{17}O$ value (Rao et al., unpublished data), further supporting the theory of atmospheric formation of natural ClO_4^- via O_3.

Dual isotope plots comparing δ^{37}Cl versus δ^{18}O and Δ^{17}O versus δ^{18}O in natural and synthetic ClO_4^- are provided in Figure 3.4. The plots are composed of data collected to date from the published literature (Sturchio et al., 2006, 2011; Böhlke et al., 2009; Jackson et al., 2010). These isotope data are also provided in Appendix A. The mean values for Chilean ClO_4^- for δ^{37}Cl, δ^{18}O and Δ^{17}O are -12.6 ± 1.5 ‰ (n = 13), -6.6 ± 2.1 ‰ (n = 17) and +9.2 ± 0.7 ‰ (n = 17), respectively. One anomalous value from Bao and Gu, (2004), labeled with an asterisk in Plot B, is excluded from the above averages, but additional samples have been collected from different regions of the Atacama Desert to provide a more reliable determination of the range in Δ^{17}O. The isotope data from these samples are not yet available (ESTCP Project ER-200509).

As shown in the dual isotope plots in Fig 3.4, there are consistent and significant isotopic differences between natural Chilean ClO_4^- and synthetic ClO_4^-. Most significantly, the high Δ^{17}O values for the Chilean materials (average of +9.2 ‰) clearly differentiate this ClO_4^- source from all synthetic sources, for which the average value Δ^{17}O value is near 0, consistent with typical mass-dependent isotopic fractionation of ^{16}O, ^{17}O, and ^{18}O (Fig 3.4, Plot A). The low δ^{37}Cl values (average of -12.6 ‰) also clearly distinguish Chilean ClO_4^- from all synthetic sources, which have an average δ^{37}Cl value of +0.8 ‰. Thus, both Δ^{17}O and δ^{37}Cl can be used to differentiate these two sources in forensic studies.

3.2.2 Indigenous Sources in the Southwestern U.S.

As previously discussed in Section 1.1.3, research conducted during the past decade has revealed that natural ClO_4^- occurs in arid environments other than the Atacama Desert of Chile. Most significantly for forensic studies in the U.S., indigenous natural ClO_4^- has been widely detected in the southwestern U.S., as evidenced through various surveys of ClO_4^- in surface soils, vadose-zone profiles, wet and dry deposition, and groundwater in New Mexico, Texas, California and elsewhere in this region (Dasgupta et al., 2006; Plummer et al. 2006; Rajagopalan et al. 2006, 2009; Rao et al. 2007; Parker et al. 2008; Jackson et al., 2010). Recent detections of ClO_4^- in Antarctic soils and on Mars have caused additional interest in the mechanisms of formation and accumulation of natural ClO_4^- (Hecht et al. 2009; Ming et al. 2010; Catling et al. 2010; Kounaves et al. 2010).

The stable isotopic composition of indigenous natural ClO_4^- from several locations and environments (vadose zone, caliche deposits, groundwater) in the southwestern U.S. was reported recently by Jackson et al. (2010). One group of groundwater samples was collected from a large area of the Southern High Plains (SHP) of West Texas and New Mexico (n = 8), and the Middle Rio Grande Basin (n = 2) (grouped together with "Southern High Plains" in Figure 3.4). One soil sample from West Texas was also analyzed. All of these indigenous samples are similar isotopically, despite the large areal extent over which they were collected, with δ^{37}Cl values ranging from +3.1 to +5.0 ‰, δ^{18}O values ranging from +0.6 to +3.8 ‰, and Δ^{17}O values ranging from +0.3 to +1.3 ‰. The data indicate that ClO_4^- from the SHP region of Texas and New Mexico is consistently different from both Chilean ClO_4^- and synthetic ClO_4^- when all relevant stable isotopic abundances are considered (^{16}O, ^{17}O, ^{18}O, ^{35}Cl and ^{37}Cl) (Figure 3.4). The small, but significantly positive Δ^{17}O values of these samples indicate that either (1) they were formed predominantly by a different mechanism than the Chilean ClO_4^-, which has much higher average Δ^{17}O (hypothesized to originate from O_3 as a reactant) or (2) the ClO_4^- was affected by post depositional O exchange (see Section 3.3 for additional information on post depositional reactions).

A second group of ClO_4^- samples (n = 4) represented in Fig 3.4 was collected from NO_3^--rich caliche deposits around the southern end of Death Valley, California within the Mojave Desert (see map in Jackson et al., 2010). These deposits, which have ClO_4^- concentrations ranging from 0.25 to 1.7 mg/kg (about 1-3 orders of magnitude lower than the Atacama deposits) are characterized by ClO_4^- with an isotopic signature that is distinctive from the Chilean and synthetic ClO_4^-, and from those from the SHP. In comparison to the SHP samples, the Death Valley samples have lower δ^{37}Cl values (from -0.8 to -3.7 ‰) and much higher Δ^{17}O values (+8.6 to +18.4 ‰). As is apparent from Fig 3.4, Plot B, the Δ^{17}O values of the Death Valley samples are similar to or, in some instances, higher than those of the Chilean samples, indicating an important component of atmospheric origin and relative lack of post depositional exchange of O with terrestrial materials. The SHP and Death Valley samples can be considered together as U.S. indigenous sources and, even though there are substantial ranges in the individual isotope values, this indigenous grouping remains isotopically distinct from synthetic and Chilean ClO_4^- when all relevant isotopes are considered.

Figure 3.3. Values of $\Delta^{17}O$ versus $\delta^{18}O$ in Chilean and synthetic ClO_4^-. The single value with an asterisk is from Bao and Gu (2004).

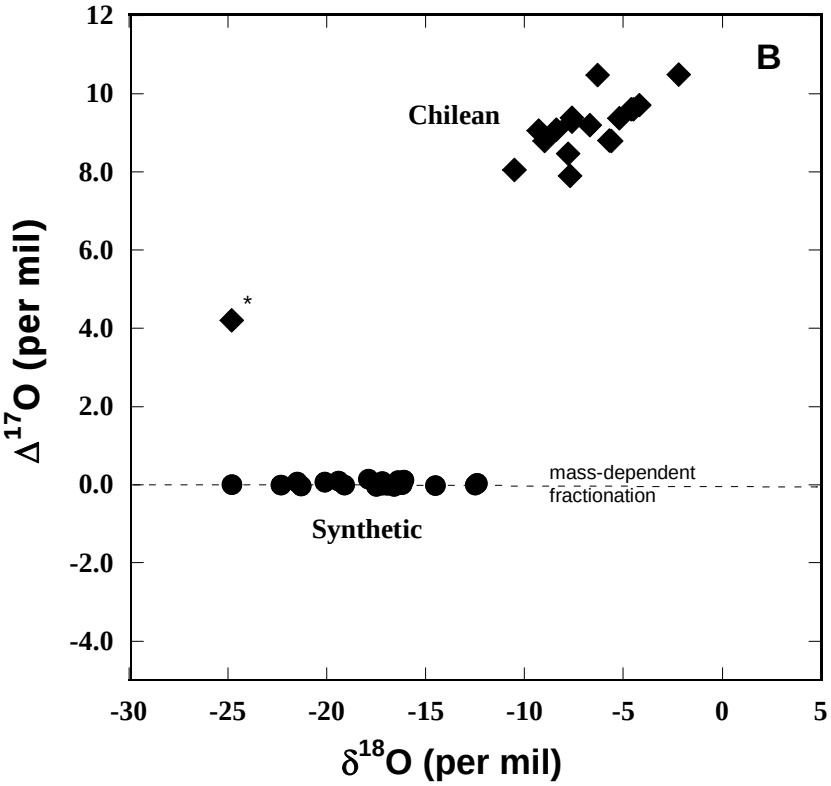
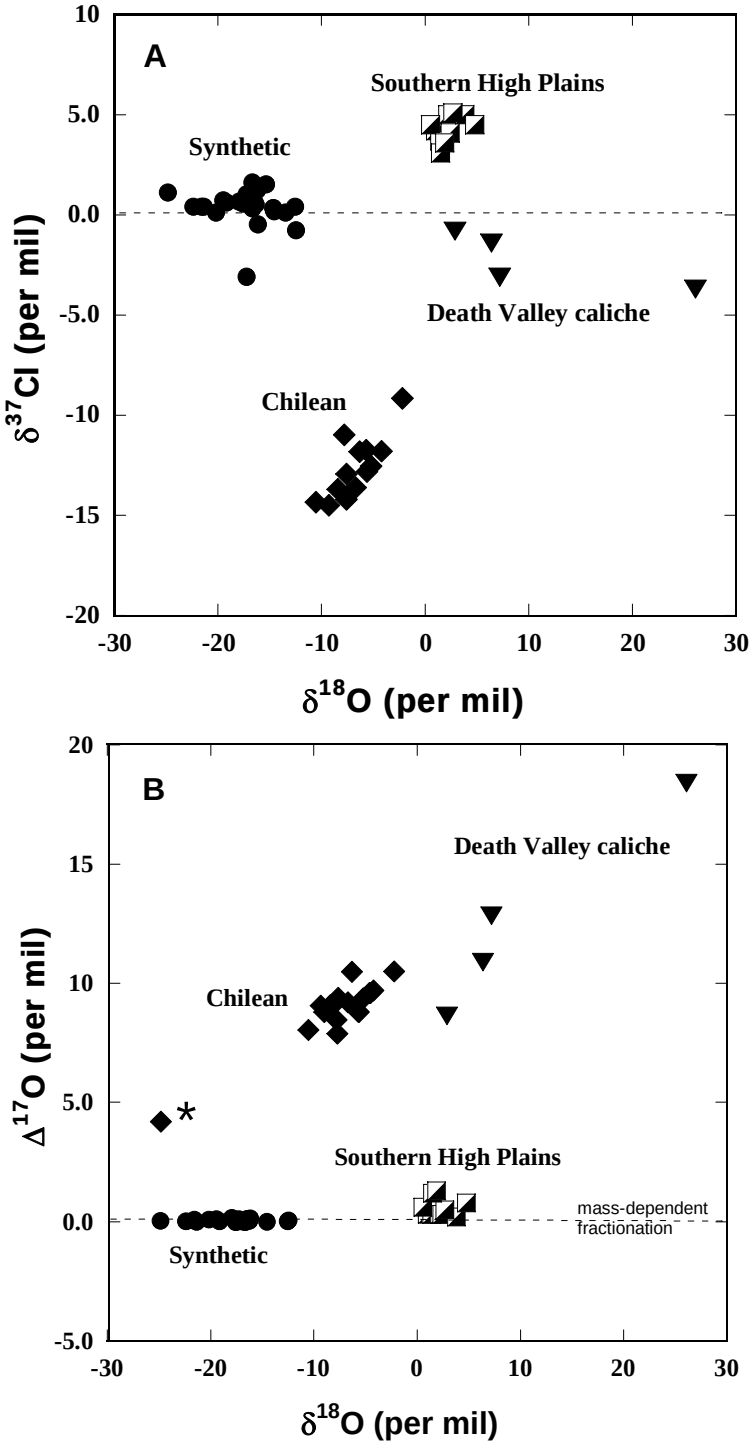


Figure 3.4. Comparison of δ^{37}Cl versus δ^{18}O (Plot A) and Δ^{17}O versus δ^{18}O (Plot B) in natural indigenous ClO_4^- in the U.S., natural Chilean ClO_4^-, and synthetic ClO_4^-. The single value on Plot B labeled with an asterisk from Bao and Gu (2004) is distinct from all other results from Chilean samples reported to date.



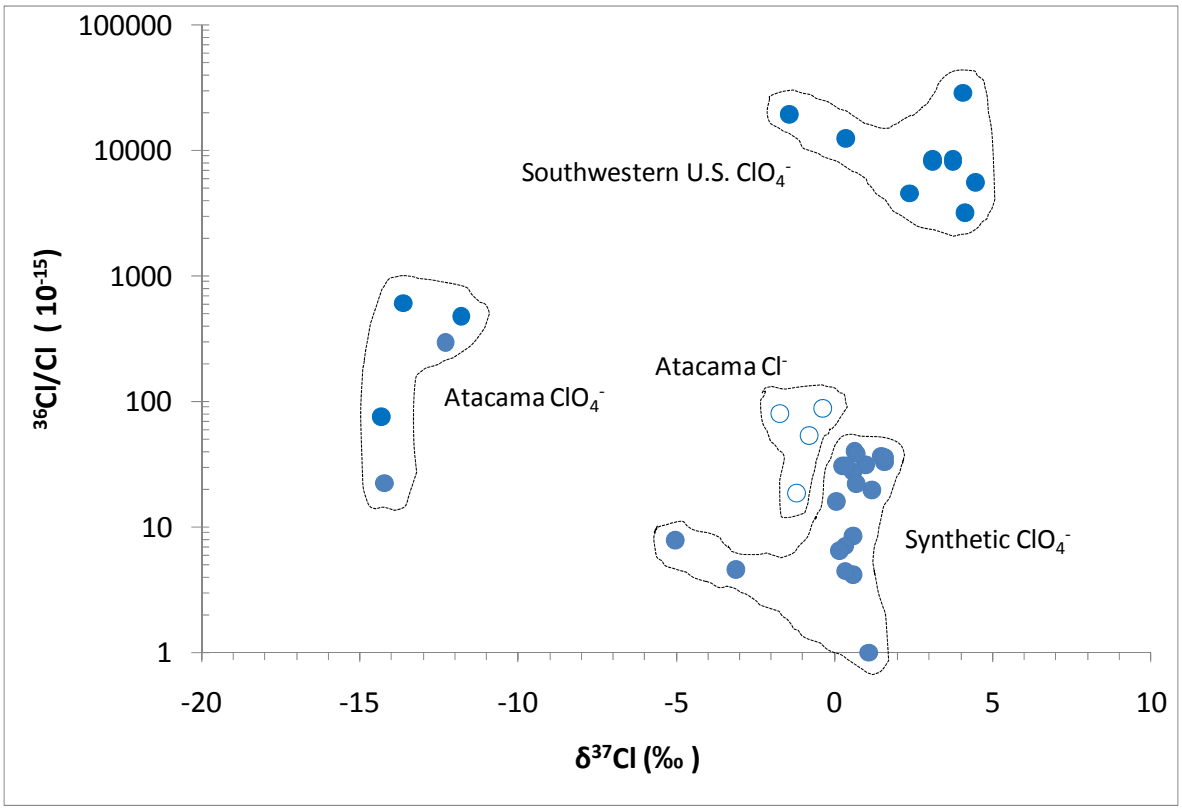
3.3 Abundance of ^{36}Cl in Synthetic and Natural Perchlorate

The abundance of the radioactive isotope ^{36}Cl (reported as atom fraction, or mole fraction, designated traditionally as ^{36}Cl/Cl) has proven to be another important tool for distinguishing ClO_4^- sources (see Section 2.6 for additional background). Chlorine-36 is present naturally in Cl^- in groundwater in the U.S., with ^{36}Cl/Cl values ranging from ~10 × 10^{-15} near coasts to as high as ~ 1700 × 10^{-15} in the central Rocky Mountains (Bentley et al., 1986; Phillips, 2000; Davis et al., 2003). Until recently, values of ^{36}Cl/Cl in ClO_4^- were unknown. However, Sturchio et al. (2009) reported values of ^{36}Cl/Cl in 35 different ClO_4^- samples from synthetic, Chilean, and Southwestern U.S. sources ranging over more than four orders of magnitude (Figure 3.5). Synthetic ClO_4^- samples were characterized by relatively low values of ^{36}Cl/Cl from 0 × 10^{-15} to 40 × 10^{-15} (Sturchio et al., 2009). These values are consistent with Cl sources such as the geologically ancient halite-rich evaporate deposits (e.g., salt domes, bedded salts) from which large amounts of NaCl are mined commercially in the form of rock salt.

In contrast to synthetic samples, all indigenous natural ClO_4^- samples from the Southwest U.S. that were tested (including some of the SHP groundwater samples and Death Valley deposits described in Section 3.2.2 and shown in Fig 3.4 with differing δ^{37}Cl and Δ^{17}O) had unusually high ^{36}Cl/Cl values, ranging from 3130 × 10^{-15} to 28,800 × 10^{-15}. The presence of bomb-generated ^{36}Cl from nuclear tests in the mid 1950's (Phillips, 2000; Davis et al., 2003) could not be ruled out for a few of the samples, but ^{36}Cl/Cl values as high as 12,300 × 10^{-15} were measured in ClO_4^- from groundwater in New Mexico with recharge ages estimated at > 5,000 yr (Plummer et al., 2006; Sturchio et al., 2009). High concentrations of ^{36}Cl in some ClO_4^- samples may point toward the stratosphere, rather than the troposphere, as an important area of atmospheric ClO_4^- formation (Sturchio et al., 2009). Natural ClO_4^- from Chilean deposits had ^{36}Cl/Cl values from 22 × 10^{-15} to 590 × 10^{-15}, much lower than any of the natural samples from the Southwest U.S. The Chilean samples originally may have had high ^{36}Cl/Cl values resulting from stratospheric production, but may have lost much of that activity via radioactive decay. This could be consistent with a relatively long history of Atacama ClO_4^- accumulation, as hyper-arid conditions in this region may have persisted for at least 3 to 8 Myr (Alpers and Brimhall, 1988; Hartley and Chong, 2002), which is 10 or more times the

half-life of ^{36}Cl. Values of $^{36}Cl/Cl$ in Cl^- from the Atacama Desert are similar to those of the associated ClO_4^- as shown in Figure 3.5. The accumulation time of ClO_4^- in the arid southwest U.S. appears to have been much shorter (of the order of 10^4 yr), and natural ClO_4^- accumulated from the atmosphere during this time would be expected to possess most of its original ^{36}Cl activity (Jackson et al., 2010). Most importantly for forensic studies of ClO_4^-, in combination with stable isotope ratios of O and Cl, ^{36}Cl abundances can provide important supporting data to help differentiate synthetic, Chilean, and indigenous U.S. sources.

Figure 3.5. Values of $^{36}Cl/Cl$ (mole fraction) versus $\delta^{37}Cl$ in representative samples of synthetic ClO_4^- reagents and products, natural ClO_4^- extracted from soil and groundwater from the Atacama Desert, Chile, and natural ClO_4^- extracted from groundwater and soil from the southwestern U.S. (modified from Sturchio et al. 2009)**.**



3.4 Post Depositional Modification of Chlorine and Oxygen Isotopes in Perchlorate

One important premise of a forensic investigation involving stable isotopes is that either (1) the stable isotope signatures in a molecule are preserved after deposition (by either natural mechanisms or contamination with synthetic sources) or (2) if they are not preserved, they are modified by known processes in a predictable fashion. One of the processes that is well known to alter the stable isotope composition of a molecule is biodegradation (e.g., Sharp, 2007; Hunkeler et al., 2008). In fact, systematic enrichments in the heavier isotopes of elements in reactive compounds (e.g., ^{13}C in MTBE, ^{15}N and ^{18}O in NO_3^-) have been used extensively to document biodegradation and to estimate kinetics of the process. Other processes, including isotopic exchange with surrounding compounds, can also alter isotope values in a compound of interest, and must be evaluated. The isotopic effects of biodegradation on both Cl and O in ClO_4^- have been investigated in both laboratory and field experiments during the past few years (see Section 3.4.1), and studies are currently ongoing to evaluate the potential isotopic effects of O exchange between ClO_4^- and other environmental components including H_2O (Section 3.4.2).

3.4.1 Isotopic Fractionation of Chorine and Oxygen during Perchlorate Biodegradation

The fractionation of Cl and O stable isotopes through microbial reduction of ClO_4^- has been investigated in laboratory studies with pure cultures and in a field experiment involving a push-pull test (Coleman et al., 2003; Sturchio et al., 2003, Sturchio et al., 2007, Hatzinger et al., 2009). The equations used to describe isotopic fractionation of reactants are provided below (from Sturchio et al., 2007):

The isotopic fractionation factor, α, is defined as

[Eq. 3.1] $$\alpha = R_A/R_B$$

where R is an isotope ratio (Equation 3.1), and A and B are two compounds (product and reactant, respectively). For O and Cl isotope ratios, R represents $N(^{18}O)/N(^{16}O)$ or $N(^{37}Cl)/N(^{35}Cl)$, respectively, where N is number of entities (atoms). Values of α can be obtained from experimental data by assuming the exponential function:

[Eq. 3.2] $R/R_0 = f^{\alpha-1}$

where R and R_0 are the O or Cl isotope ratios of the residual ClO_4^- and the initial (unreacted) ClO_4^-, respectively, and f is the fraction of ClO_4^- remaining. The δ values of ClO_4^- are calculated using the following relationship:

[Eq. 3.3] $(\delta + 1)/(\delta_0 + 1) = f^{\alpha-1}$

where δ is the isotopic composition of the ClO_4^- at any value f, and δ_0 is the isotopic composition at $f = 1$. The value of α can be calculated from the natural logarithm of Eq 3.2 as shown below:

[Eq. 3.4] $\alpha\text{-}1 = \ln (R/R_o)/\ln f$

The relation in Eq 3.4 describes the mass-dependent Rayleigh-type isotopic fractionation that accompanies a variety of natural processes (Clark and Fritz, 1997; Broecker and Oversby 1971). Isotopic fractionation factors are commonly expressed in terms of ε, where

[Eq. 3.5] $\varepsilon = \alpha - 1,$

with ε typically reported in parts per thousand, or per mil (‰). Two independent studies evaluating the isotopic fractionation of Cl in ClO_4^- by the bacterial species A*zospira suillum* with acetate as the electron donor and ClO_4^- as the sole electron acceptor, reported ε^{37}Cl values ranging from -12.9 ‰ to -16.6 ‰ depending on culture conditions (Coleman et al. 2003; Sturchio et al. 2003). Data for both Cl and O isotopic fractionation during microbial reduction of ClO_4^- were reported subsequently by Sturchio et al. (2007) using two bacterial genera (*Azospira* and *Dechlorospirillum*), each incubated at two different temperatures (22 °C and 10 °C, respectively). This study also evaluated the potential for O exchange during biodegradation of ClO_4^- using ^{18}O-enriched H_2O. The ε^{37}Cl values in the various experimental treatments varied from -14.5 to -11.5 ‰, and ε^{18}O values ranged from -36.6 to -29.0 ‰. The ε values were independent of bacterial strain and temperature, and there was no evidence for O exchange between ClO_4^- and H_2O. One critical finding from

this work was that the ratio of $\varepsilon^{18}O/\varepsilon^{37}Cl$ was nearly constant in all experiments (independent of strain or temperature or rate of reaction) at 2.50 ± 0.04 over a range of f from 1.00 to 0.01 (Figure 3.6).

In a subsequent field study, water with ClO_4^- was injected into an aquifer that had previously been treated with soybean oil emulsion to stimulate ClO_4^- biodegradation, and then samples were collected over time from the injection well for analysis of stable isotopes and geochemical parameters (Hatzinger et al., 2009). The *in situ* isotopic fractionation factors ($\varepsilon^{37}Cl$ and $\varepsilon^{18}O$) from this study were 0.3-0.4 times the values previously reported for pure cultures, and the differences were attributed to physical and chemical heterogeneity in the aquifer. Similar effects have been observed during a number of other field studies of *in situ* isotopic fractionation, and modeling has illustrated how physical processes in heterogeneous hydrologic systems can cause field isotopic fractionation data to differ from lab data (Mariotti et al., 1988; Brandes and Devol, 1997; Green et al., 2010). Nonetheless, despite the differences in the magnitudes of the individual isotope effects, the $\varepsilon^{18}O/\varepsilon^{37}Cl$ ratio was 2.6, which is in excellent agreement with the laboratory-determined value of 2.5 as shown in Figure 3.6 and described further below (Sturchio et al. 2007). This indicates that the fundamental process by which ClO_4^- is reduced was the same in laboratory and field settings, but the heterogeneity of the field setting is such that it can lead to underestimation of the extent of ClO_4^- reduction when using an isotopic approach based solely on laboratory fractionation factors (Hatzinger et al., 2009).

The previous laboratory and field results concerning isotopic fractionation during biodegradation have implications for forensic studies. Isotopic analyses of O and Cl in ClO_4^- clearly show that different sources have distinct isotopic compositions, as described in Sections 3.1 and 3.2. However, variations in the isotopic composition of ClO_4^- in field samples could theoretically be caused by biodegradation or by mixing of isotopically distinct sources, and it is important to resolve these effects. Based on the laboratory and field studies conducted to date, biodegradation of ClO_4^- causes both $\delta^{18}O$ and $\delta^{37}Cl$ in the residual ClO_4^- (i.e., that remaining in the environment) to move along the slope shown in

Figure 3.7. This trajectory (the slope of which is constant at $\varepsilon^{18}O/\varepsilon^{37}Cl$ = 2.5) is roughly perpendicular to the area in which mixtures of synthetic and Chilean ClO_4^- would plot. Thus, biodegradation will not obscure the difference between these two major sources. In Figure 3.7, the *f* values plotted on the upper sloping line indicate the calculated values of $\delta^{18}O$ and $\delta^{37}Cl$ in synthetic ClO_4^- when 10 % (*f* = 0.9), 20 % (*f* = 0.8), etc. are biodegraded, according to the lab data. Based on the field results of Hatzinger et al. (2009), the *f* values would remain much closer to the source material (i.e., at 30 % biodegraded, the $\delta^{18}O$ and $\delta^{37}Cl$ values are predicted to be near *f* = 0.9 on the curve in Figure 3.7). Different field settings might yield somewhat different degrees of scale contraction along this fractionation line. Most critically, however, the slope of the progression of $\varepsilon^{18}O/\varepsilon^{37}Cl$ is the same in the flask and field, such that synthetic and Chilean ClO_4^- will not overlap isotopically as a result of biodegradation.

The $\delta^{18}O$ and $\delta^{37}Cl$ values for ClO_4^- derived from the SHP place this material near the trajectory for a small subset of synthetic ClO_4^- samples as shown in Figure 3.8. The synthetic samples with the highest $\delta^{18}O$ values (i.e., ~ -15 ‰) could overlap with SHP samples if they were extensively biodegraded. Similarly, it is possible that $\delta^{18}O$ and $\delta^{37}Cl$ values for a Chilean ClO_4^- sample could become similar to those from Death Valley if the Chilean ClO_4^- were substantially biodegraded. However, it is important to note that $\Delta^{17}O$ values are almost unaffected by mass-dependent processes, so that large differences in $\Delta^{17}O$ between the sources would be preserved during degradation while $\delta^{18}O$ and $\delta^{37}Cl$ values were changing. Thus, from a practical perspective, potential "overlaps" in stable isotopic compositions caused by isotope effects of biodegradation are unlikely to cause mistakes in source delineation, particularly if ^{36}Cl analyses are conducted for samples and other supporting chemical and geochemical data are collected from sampling locations. For example, the potential for highly biodegraded (and isotopically fractionated) synthetic ClO_4^- to be confused for SHP natural ClO_4^- because of overlapping values of $\delta^{18}O$ and $\delta^{37}Cl$ can be further minimized by analyzing all samples in a forensic investigation for ^{36}Cl, as synthetic samples have low $^{36}Cl/Cl$ values (0×10^{-15} to 40×10^{-15}), whereas SHP and Death Valley samples have much higher $^{36}Cl/Cl$ values (3130×10^{-15} to $28{,}800 \times 10^{-15}$) (Sturchio et al., 2009), and these values should not be affected significantly by

biodegradation. Similarly, Chilean and Death Valley samples analyzed to date have very different $^{36}Cl/Cl$ values.

In addition to ^{36}Cl, local geochemical parameters, including oxidation-reduction potential (ORP) and concentrations of dissolved O_2 (DO), organic carbon (DOC), NO_3^-, and N_2 (see Section 2.8) can provide important constraints on the potential for biodegradation. Bacteria require an organic or inorganic electron donor, as well as anoxic conditions to biodegrade ClO_4^- (Coates and Achenbach, 2004), and NO_3^- has been observed to impede biodegradation for many (but not all) ClO_4^- reducing strains (Farhan and Hatzinger, 2009; Chaudhuri et al., 2002). Thus, in aquifers with historically high levels of DO, ORP, and/or NO_3^-, biodegradation of ClO_4^- is unlikely. Similarly, low DOC (as one measure of potential organic electron donor abundance) also will limit biodegradation. Finally, when conditions are correct for ClO_4^- biodegradation, rates of this process are often very rapid and complete (making *in situ* and *ex situ* bioremediation viable treatment approaches; Hatzinger, 2005), unlike the slow kinetics often observed during biodegradation of chlorinated solvents, MTBE, and various other pollutants for which CSIA is applied. Thus, the potential for partially biodegraded and isotopically fractionated ClO_4^- to persist in an aquifer where biodegradation is occurring is less likely than for many other traditionally recalcitrant compounds.

Figure 3.6. Relation between $\varepsilon^{18}O$ and $\varepsilon^{37}Cl$ during bacterial reduction of ClO_4^- . The data presented represent results from laboratory studies in which ClO_4^- biodegradation by two strains was measured at two different temperatures (10 °C and 22 °). The isotopic fractionation factor ratio [$\varepsilon^{18}O/\varepsilon^{37}Cl$ = 2.5] is independent of strain and temperature (figure from Sturchio et al. 2007).

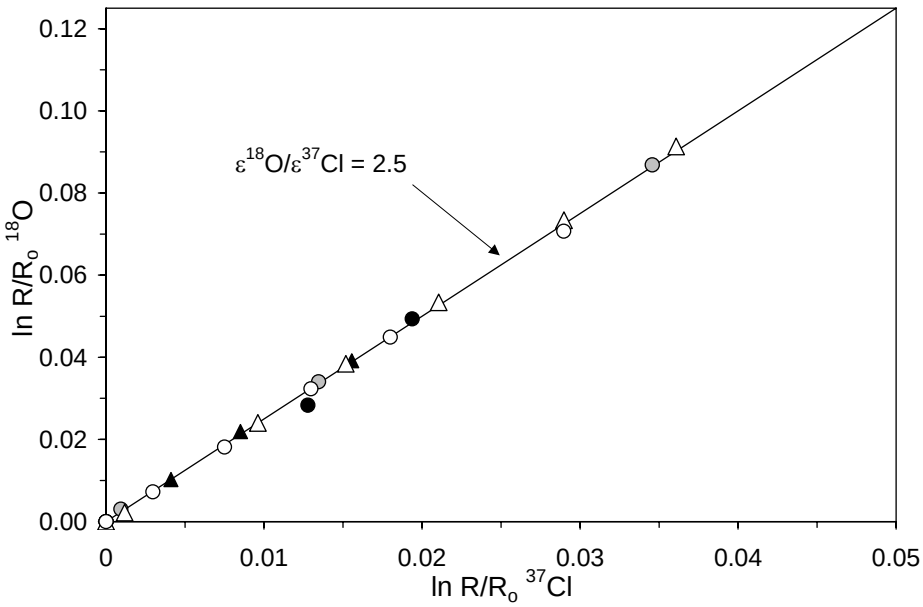


Figure 3.7. Relation between $\delta^{18}O$ and $\delta^{37}Cl$ values of synthetic and Chilean ClO_4^-, isotopic compositions of mixtures of these sources, and the isotopic compositions of residual ClO_4^- during biodegradation. The extent of biodegradation is given by *f*, the residual fraction, assuming $\varepsilon^{18}O$ = -36.25 ‰ and $\varepsilon^{37}Cl$ = -14.5 ‰; $\varepsilon^{18}O/\varepsilon^{37}Cl$ = 2.5.

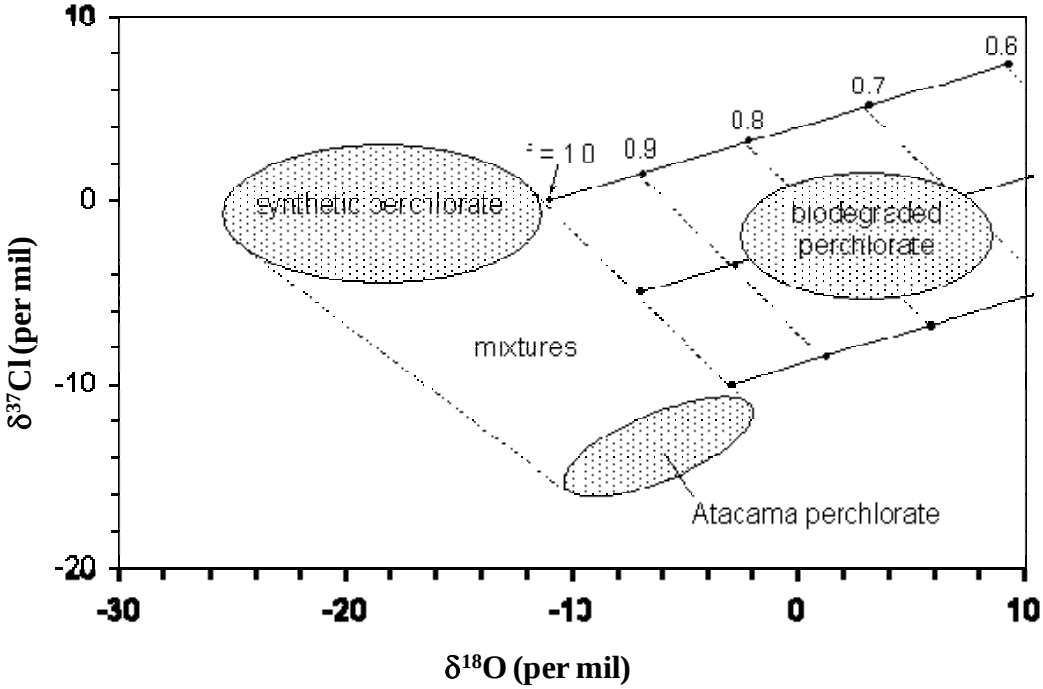
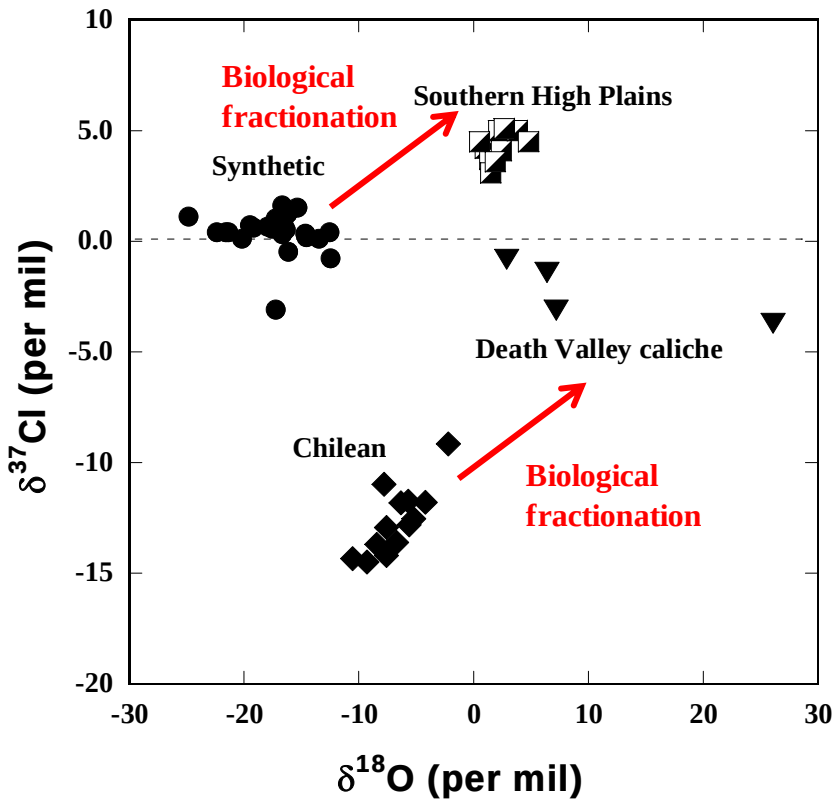


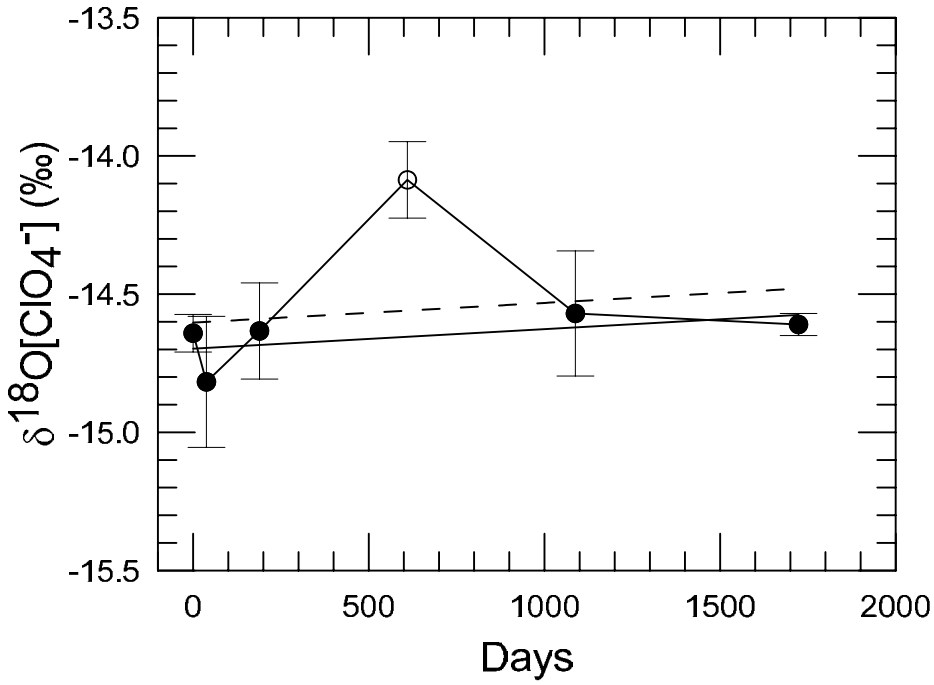
Figure 3.8. Microbial isotopic fractionation trajectory compared to $\delta^{18}O$ and $\delta^{37}Cl$ values of various ClO_4^- sources. Arrows indicate direction of change for $\varepsilon^{18}O/\varepsilon^{37}Cl = 2.5$.



3.4.2 Exchange of Oxygen between Perchlorate and Water

Besides biological isotopic fractionation, exchange of O in ClO_4^- with surrounding H_2O in an aquifer or elsewhere could lead to post depositional changes in the $\delta^{17}O$ and $\delta^{18}O$ values of ClO_4^-. Because Cl is the central atom in ClO_4^- and is bonded to four O molecules, exchange of Cl may be less likely. The USGS has been evaluating the potential for the exchange of O by ClO_4^- in a long-term study. During this evaluation, which is ongoing, ClO_4^- (from $HClO_4$) with a known O isotopic composition was mixed with ^{18}O-enriched H_2O ($\delta^{18}O$ = +156 ‰), and the mixture was sealed and incubated at room temperature (22 ± 1 °C). Periodically, subsamples of the solution are removed and the O isotopic composition of the ClO_4^- is measured by IRMS as described previously. After nearly 5 yr of incubation, evidence for exchange of O between the ^{18}O-enriched H_2O and the ClO_4^- is negligible (Figure 3.9) (JK Böhlke et al., unpublished data). Based on the current data from this study, the half-life of O isotope exchange between ClO_4^- and H_2O is > 4,500 yr. These results extend those of a previous investigation indicating minimal exchange of O between ClO_4^- and H_2O, with a half-life of > 100 yr (Hoering et al. 1958). Additional studies are ongoing to assess whether biological activity or mineral catalysts can accelerate the exchange reaction, but field data so far indicate that the integrity of the ClO_4^- source O isotopic ratios is maintained over at least several decades under normal groundwater conditions. This was indicated, for example, by the isotopic composition of known synthetic ClO_4^- near the end of a groundwater flow path with modeled transit time of around 30-50 yr from the source near Henderson, Nevada (Böhlke et al., 2005). It was indicated also by the detection of ClO_4^- with isotopic composition similar to that of Chilean nitrate fertilizer in groundwater on Long Island, New York 20-40 yr after the groundwater was recharged (Böhlke et al., 2009), as summarized in Section 4.0.

Figure 3.9. Values of $\delta^{18}O$ in ClO_4^- during long-term incubation in ^{18}O-enriched H_2O.



4.0 CASE STUDY OF PERCHLORATE SOURCE IDENTIFICATION: LONG ISLAND, NEW YORK

The information presented in this guidance manual describes three principal ClO_4^- sources that are likely to be found in soils and groundwaters in the U.S. (i.e., synthetic ClO_4^-, Chilean nitrate fertilizer-derived ClO_4^-, indigenous natural ClO_4^-) and shows that these sources are isotopically distinct when all relative stable isotope ratios of O and Cl (expressed as δ^{37}Cl, δ^{18}O, and Δ^{17}O) are taken into consideration (Bao and Gu, 2004; Böhlke et al., 2005, 2009; Sturchio et al. 2006, 2011; Jackson et al., 2010). The mole fraction of radioactive ^{36}Cl (expressed as ^{36}Cl/Cl) in the different sources also is a useful distinguishing characteristic (Sturchio et al. 2009). In addition, current results indicate that O exchange between ClO_4^- and H_2O is insignificant in water over at least decades if not centuries, so the isotopic characteristics of source ClO_4^- can be maintained in groundwater, at least on anthropogenic time scales (Böhlke et al., 2005, 2009). Finally, although ClO_4^- is subject to biodegradation under appropriate conditions (i.e., anoxic, low NO_3^-, available electron donor, presence of ClO_4^--reducing bacteria), this process results in predictable stable isotope effects that will not substantially alter Δ^{17}O or ^{36}Cl/Cl values and generally will not cause any one source to be isotopically indistinguishable from another. Thus, even if a source is partially biodegraded, the initial source(s) generally can be determined. Also, evaluation tools exist to determine the likelihood that biodegradation has affected ClO_4^- by examining other chemical indicators in a sample.

Based on these findings, several source-attribution studies involving unknown sources of ClO_4^- have been conducted using stable isotopic analysis, traditional hydrogeological investigations, and many of the supporting geochemical parameters described in Table 2.1. These studies were conducted in Pasadena, California (Slaten et al., 2010), San Bernardino, California (Sturchio et al., 2011), Chino, California (Chino Watermaster, unpublished data), Long Island, New York (Böhlke et al., 2009), and near the Stringfellow Superfund Site in Glen Avon, California (Hatzinger, 2008). Data from the Stringfellow study, which showed the presence of Chilean fertilizer-derived ClO_4^- in addition to synthetic sources, have been used by the California Department of Toxic Substance Control (DTSC) to explain the distribution of low levels of ClO_4^- in groundwater in some areas of the Stringfellow site.

(http://www.dtsc.ca.gov/SiteCleanup/Projects/upload/Stringfellow_FS_Update_0329100.pdf). We are aware of other studies that are currently ongoing, but for which there are currently no published data.

One of the previous studies, from Long Island, New York, is summarized below as a case study of the application of the ClO_4^- stable isotope methodology described herein for environmental forensic studies when sources are unknown. The reader is encouraged to review the published papers for additional details on this study, as well as others noted above that are not included in this document.

4.1 Characteristics of Sites and Wells

The objective of this forensic evaluation was to assess probable sources of ClO_4^- in groundwater at multiple locations within Suffolk County on Long Island, New York. The full details are presented in Böhlke et al. (2009). Perchlorate has been detected in groundwater in numerous locations on Long Island, with various sources possible based on current and past activities (Abbene, 2006; Munster, 2008). These sources include fireworks production and use, agricultural fertilizer application (historical and current), road flares, military facilities including missile launch sites, disinfection with bleach, and others. Groundwater in which ClO_4^- was previously detected was sampled using IX columns, as described in Section 2.2 of this document. The well locations are shown in Figure 4.1. Samples were collected from two production wells in the Northport area of western Suffolk County by placing an IX column on a slipstream from each well, as shown in Figure 4.2. These wells, which are screened 93 ± 10 m and 117 ± 9 m below ground surface (bgs) are within the Magothy aquifer. This region was primarily agricultural in the 1950s, but much of the land is now residential. Samples were also obtained from two shallow groundwater monitoring wells at a former BOMARC (Boeing and Michigan Aerospace Research Center) missile site near Westhampton, New York. This site was deactivated in 1969 and was converted to a training facility for police by Suffolk County. Activities at the site at the time of this study included weapons training and fireworks disposal by open burning in a pit. Both wells were upgradient from the former missile silos and downgradient from a firing range and fireworks disposal pit. Finally, a monitoring well transect was sampled in the North Fork area in the northeast part of Suffolk County (Depot Lane). This transect

consisted of three nested monitoring wells running in a northwest-southeast array across the middle of the North Fork Peninsula. Land use in this area is primarily agricultural. These wells are screened within the surficial upper glacial aquifer (Schubert et al., 2004). The deepest well screens are just above a lower confining unit, which begins at approximately -35 to -31 m elevation (Bohn-Buxton et al., 1996).

Figure 4.1. Location map of groundwater wells sampled for ClO_4^- source identification on Long Island, New York (modified from Böhlke et al., 2009).

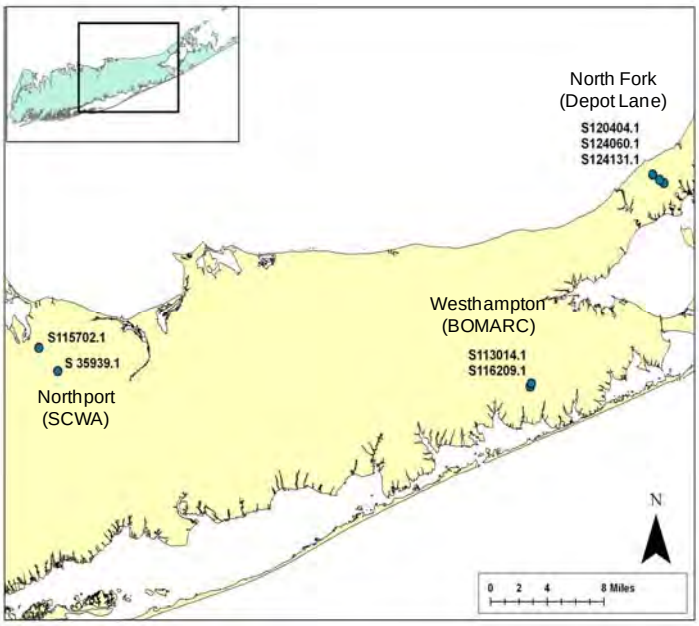


Figure 4.2. Sample collection setup for ClO_4^- from a public supply well on Long Island, New York.

4.2 Sample Collection and Analyses

Groundwater field parameters were measured at each well (DO, pH, conductivity, and temperature) and samples were collected essentially as described in Section 2.8.1 of this document, with supporting parameters as summarized previously in Table 2.1. In addition to IX columns for ClO_4^- collection for Cl and O isotopic analyses, groundwater samples were collected for isotopic analyses of N, S, and O in NO_3^- and SO_4^{2-}, for concentration analyses of ClO_4^-, anions, trace elements,, and major dissolved gases (Ar, N_2, O_2, and CH_4), and for groundwater-age dating (^3H, ^3He, SF_6, and chlorofluorocarbons (CFCs) as described in Section 2.8 and Table 2.1). Samples were obtained between December 2006 and April 2008.

4.3 Results of Chlorine and Oxygen Isotopic Analyses of Perchlorate

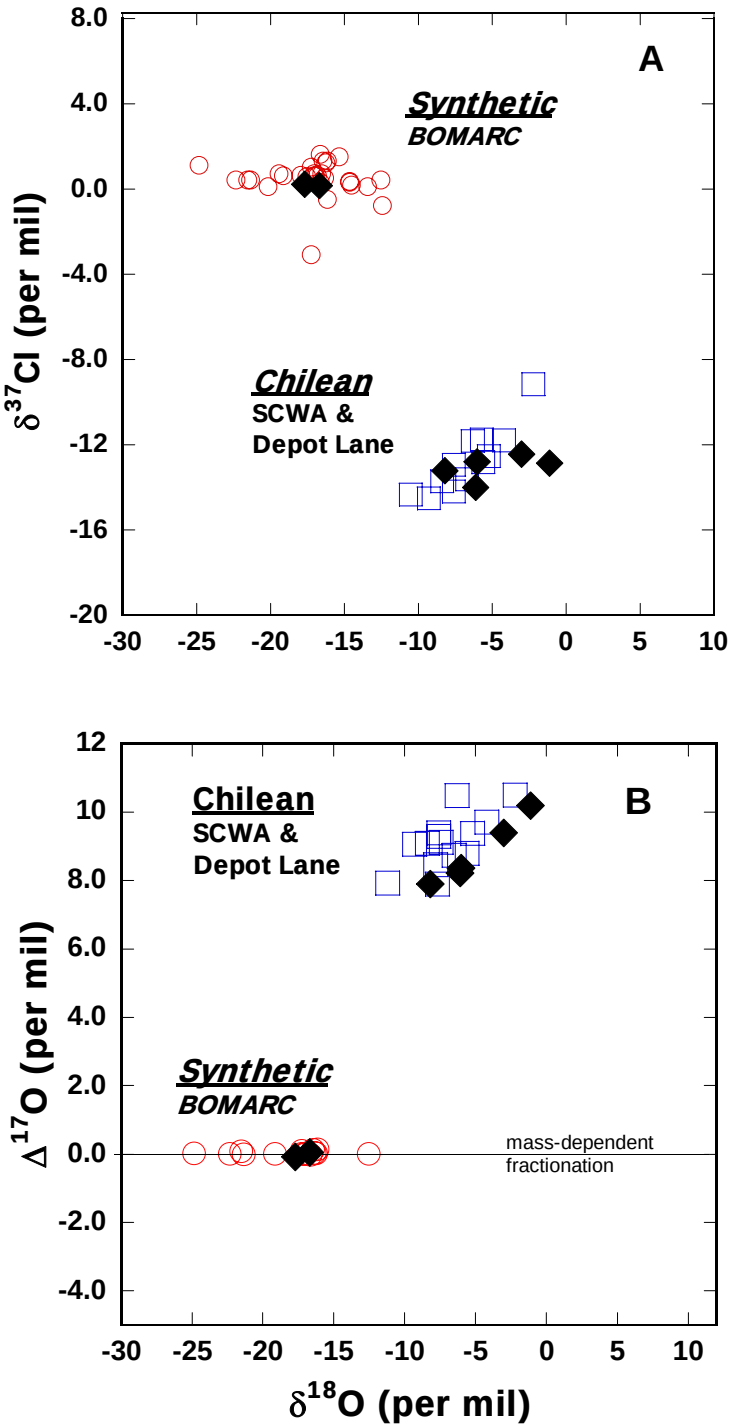
Perchlorate was detected at the highest concentrations at the former BOMARC site (~ 360 – 4,300 μg/L), where fireworks disposal and military activities were considered the most likely sources. The Suffolk County production wells had ClO_4^- concentrations of 8.4 to 11.2 μg/L and the deep nested wells at Depot Lane had concentrations from ~ 4.6 to 10 μg/L. The shallow nested wells at Depot Lane had concentrations of only 0.2 to 1.0 μg/L, which was too low to permit collection of samples for isotopic analysis using available equipment and site access. The $\delta^{37}Cl$, $\delta^{18}O$, and $\Delta^{17}O$ values of the ClO_4^- collected from the BOMARC wells (n = 2) were consistent with values typical of synthetic ClO_4^-, while samples from the Northport production wells (n = 2) and the deep Depot Lane wells (n = 3) were consistent with natural ClO_4^- from Chile (Figure 4.3). There was no indication of ClO_4^- biodegradation or denitrification (see Böhlke et al., 2009 for data) in the site groundwater.

The two BOMARC wells, which contained unusually high concentrations of ClO_4^-, were near a fireworks disposal pit. The groundwater in the wells also had anomalously high concentrations of K, Sr, and Sb, as determined by ICP-MS analysis. These elements commonly are used for color and brightness in fireworks (Conklin, 1985). Although various local sources of synthetic ClO_4^- may be present at this site, leaching of unexploded fireworks as the cause of groundwater contamination is supported by presence of a

fireworks disposal pit in the area, the extremely high ClO_4^- levels in each of the wells, the anomalously high concentrations of trace elements common to many fireworks, and the young ages of the groundwaters (1-2 yr, based on environmental tracer data).

In contrast to the BOMARC wells, the Cl and O isotopic compositions of ClO_4^- from the Depot Lane wells and Northport production wells were consistent with ClO_4^- found in Chilean nitrate deposits and fertilizers. Groundwater in these wells also had relatively high concentrations of NO_3^- and other constituents that are typical of recharge beneath fertilized agricultural land in this region, such as Ca, Mg, and SO_4^{2-} (see Böhlke et al., 2009 for data and further explanation). No other ClO_4^- sources, including the U.S. indigenous sources, are currently known to have the distinctive combination of low δ^{37}Cl, low δ^{18}O, and high Δ^{17}O values that characterize the Chilean ClO_4^-. Thus, the data indicate that the ClO_4^- in these wells was derived from the historical use of Chilean nitrate fertilizers on Long Island. Age dating of groundwater supports this hypothesis (see Section 4.4 and Figure 4.4B). It is apparent from the data that the distinctive Cl and O isotopic compositions of the Chilean ClO_4^- were not altered substantially by O exchange or other plant, soil, or mineral reactions during transport and aging in the Long Island aquifers.

Figure 4.3. Comparison of δ^{37}Cl versus δ^{18}O (Plot A) and Δ^{17}O versus δ^{18}O (Plot B) in ClO_4^- from wells on Long Island with those of synthetic and Chilean source materials. The data from the Long Island wells are plotted as black diamonds, the data from synthetic sources as open red circles, and those from Chilean samples as open blue squares.



4.4 Groundwater-Age Dating and Other Supporting Data

Groundwater-age dating provided valuable information during this study. Apparent recharge dates and ages of groundwater (time in saturated zone after recharge) were estimated from concentrations of various atmospheric tracers including ^{3}H-^{3}He, SF_6, and CFCs, as summarized in Böhlke et al. (2009). Based on the tracer data, a composite mean apparent age was estimated for groundwater in each well, and the results ranged from ~ 1 to 41 yr with uncertainties of the order of 2-5 yr. The groundwater in the BOMARC wells was recharged within the previous 2 yr prior to groundwater sample collection. The presence of recently recharged water is consistent with fireworks from the disposal pit area as a source of ClO_4^- contamination. At the North Fork (Depot Lane) transect wells, apparent groundwater ages ranged from ~ 1 to 39 yr and increased with depth as did the mean concentration of ClO_4^-, while the relatively high levels of NO_3^- remained almost constant with groundwater depth and age (Figure 4.4).

The consistently lower ClO_4^- concentrations in younger groundwater, with the relatively constant NO_3^-, were interpreted by Böhlke et al. (2009) to reflect changing agricultural practices, with quantities of ClO_4^- bearing Chilean fertilizer declining and being replaced by other sources without ClO_4^- over the past several decades (possibly including low-ClO_4^- Chilean fertilizer in recent years). This groundwater trend (decreasing ClO_4^- and constant or slightly increasing NO_3^-) resembles qualitatively the overall patterns of Chilean and non-Chilean fertilizer use in the United States since the mid-1900s (Figure 4.5). This interpretation is also consistent with Chilean ClO_4^- as a source in the Northport area production wells, as the composite apparent groundwater ages at these wells were 35 and 41 yr, respectively, similar to those of the deeper wells in the Depot Lane transect that had Chilean ClO_4^-. These groundwaters apparently recharged when land use was more agricultural than at present. Data from several other locations sampled during ESTCP Project ER-200509, including sites in North Carolina, New Jersey, and several locations in California, indicate that Chilean ClO_4^- may be common in aerobic aquifers that underlie regions with an agricultural history that included applications of imported Chilean nitrate fertilizer.

4.5 Summary of Long Island Perchlorate Source Study

The stable isotope results (δ^{37}Cl, δ^{18}O, and Δ^{17}O) for ClO_4^- and key supporting chemical and environmental tracer data collected from several wells on Long Island provide strong evidence for the presence of ClO_4^- derived from Chilean nitrate fertilizer as well as that from a synthetic source, presumably fireworks disposal. The groundwater at all locations was aerobic and undenitrified, and ClO_4^- apparently was not affected isotopically by biodegradation or exchange processes in the subsurface. In an agricultural region, ClO_4^- concentrations and the ratio of ClO_4^-/NO_3^- increased with increasing groundwater age (from ~ 1 to 40 yr based on atmospheric tracers), most likely as a result of declining application rates of Chilean nitrate fertilizer. Stable Cl and O isotopic analyses of ClO_4^- indicates that past use of imported Chilean nitrate fertilizer on Long Island has led to legacy contamination of some aquifer units, even though this fertilizer may have been applied in relatively small quantities as long as 40 or more years ago.

Figure 4.4. Vertical distribution of NO_3-N and ClO_4^- concentrations in nested wells along a transect in the North Fork area of Long Island. The estimated time since recharge of the groundwater at different depths in the DL 4 well nest is also given. Figure modified from Böhlke et al (2009).

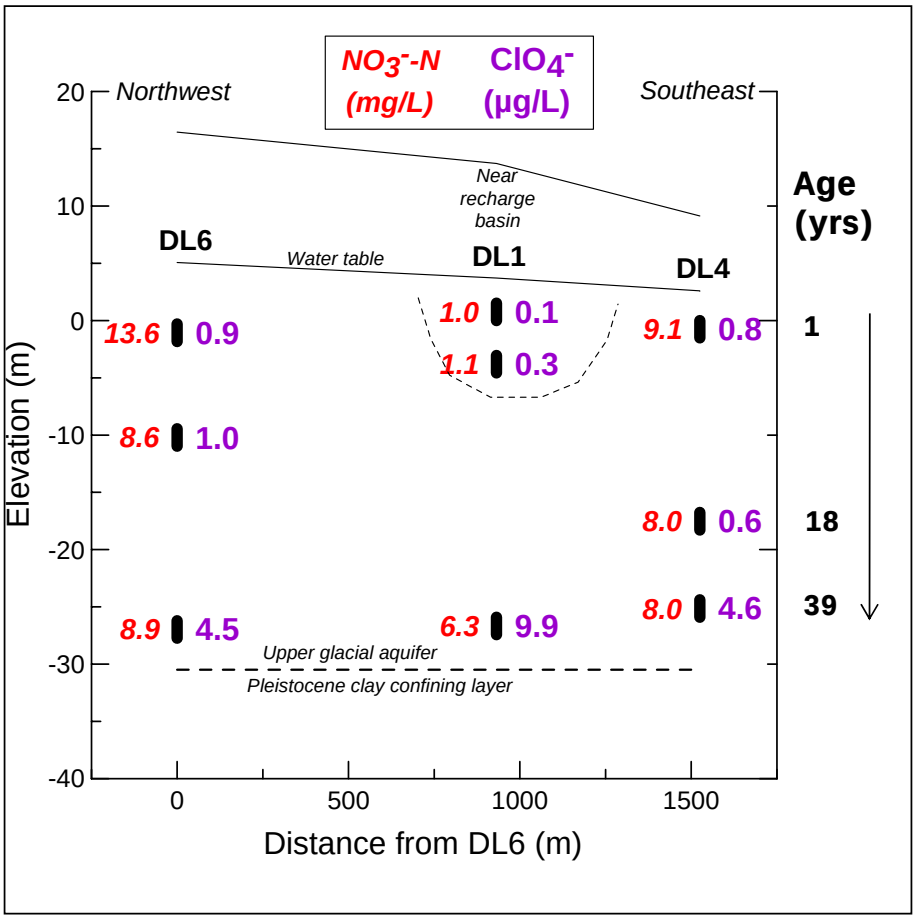
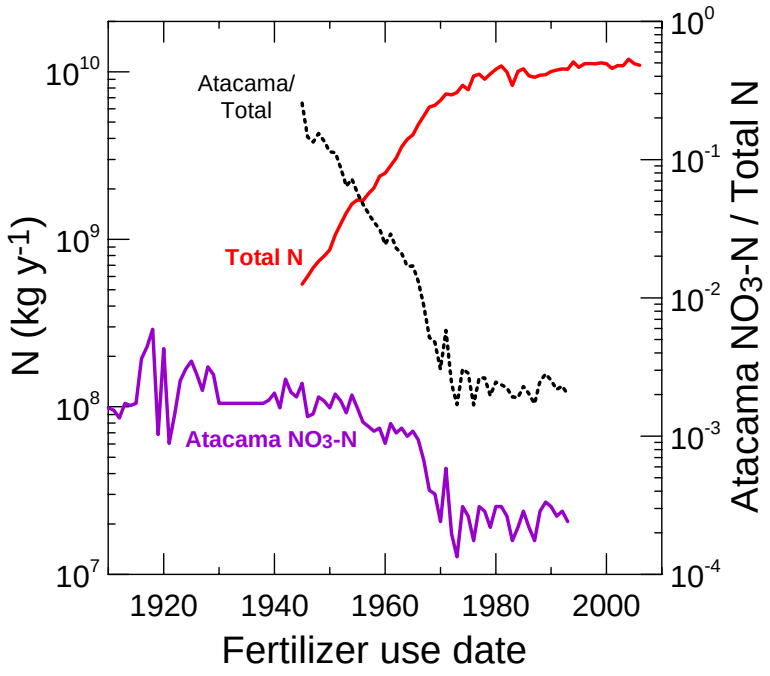


Figure 4.5. National trends of Chilean fertilizer use (Atacama NO_3^-) and total N fertilizer use in the U.S. (modified from Böhlke et al., 2009).



5.0 SUMMARY AND CONCLUSIONS

The key objective of this document is to describe isotopic techniques that can be used to discern the origin of ClO_4^- in soils and groundwater, and more specifically whether that ClO_4^- is synthetic or natural. These techniques determine the relative abundances of the stable isotopes of chlorine (^{37}Cl and ^{35}Cl) and oxygen (^{18}O, ^{17}O, and ^{16}O) in ClO_4^- using IRMS and the radioactive isotope ^{36}Cl using AMS. Taken together, these measurements on the ClO_4^- ion (which provide four independent quantities) can be used to distinguish natural from synthetic ClO_4^- sources, to discriminate different types of natural ClO_4^-, and to detect ClO_4^- biodegradation in the environment. Other isotopic, chemical, and hydrogeologic techniques that can be applied in conjunction with the Cl and O isotopic analyses of ClO_4^- to provide supporting data for forensic studies are also described.

The key points presented in this document are as follows:

1. Perchlorate (ClO_4^-) has both synthetic and natural sources, each of which contributes to its occurrence in soils and groundwater. Typical analytical methods for determining ClO_4^- concentrations do not provide direct information on its potential origin.

2. A new forensic approach for ClO_4^- has been developed, based on measurements of the stable isotopes of chlorine (^{37}Cl and ^{35}Cl) and oxygen (^{18}O, ^{17}O, and ^{16}O), and a radioactive chlorine isotope (^{36}Cl) in ClO_4^-. The basic steps in this approach are as follows:

    - Sample collection using ion exchange (IX) columns to trap mg quantities of ClO_4^- from groundwater or soil extracts;
    - Extraction and purification of ClO_4^- from IX columns;
    - Verification of sample purity via Raman spectroscopy and/or ion chromatography;
    - Analysis of stable O isotopes in ClO_4^- by IRMS;

- Analysis of stable Cl isotopes in ClO_4^- by IRMS; and
- Analysis of ^{36}Cl by AMS.

3. The data gained from these isotopic analyses can be used to distinguish natural from synthetic ClO_4^- in both source materials and environmental samples. Key isotopic characteristics of different types of ClO_4^- are as follows, based on current published results (see Appendix A):

    - Synthetic ClO_4^- produced by electrochemical reaction is characterized by a mean $\delta^{37}Cl$ value (with respect to SMOC) of 0.6 ‰ and exhibits little variation among samples (-3.1 to +1.6 ‰), more variable $\delta^{18}O$ values (with respect to VSMOW) ranging from -24.8 to -12.5 ‰, and $\Delta^{17}O$ values near 0 ‰, consistent with mass-dependent isotopic fractionation of O during ClO_4^- synthesis. This material also is characterized by low $^{36}Cl/Cl$ values (^{36}Cl mole fractions) of 0×10^{-15} to 40×10^{-15}.

    - Natural ClO_4^- from caliche deposits in the Atacama Desert of Chile, and nitrate fertilizers derived from this material, have reported $\delta^{37}Cl$ values ranging from -14.5 ‰ to -11.8 ‰, with a mean value more than 10 ‰ lower than that of synthetic ClO_4^-. Reported $\delta^{18}O$ values of Atacama ClO_4^- (-24.8 ‰ to -4.2 ‰) exhibit substantial overlap with the $\delta^{18}O$ values of synthetic ClO_4^-, but the Atacama ClO_4^- is characterized by substantially elevated values of $\Delta^{17}O$ (+4.2 to +9.6 ‰), indicating non-mass-dependent isotope effects or precursors contributed to its formation, most likely during atmospheric generation. This natural ClO_4^- has slightly elevated $^{36}Cl/Cl$ values (22×10^{-15} to 590×10^{-15}) compared to synthetic ClO_4^-.

    - Natural ClO_4^- from the southwestern U.S. varies somewhat by location and environment. Samples collected from a large area of the Southern High Plains (SHP) and the Middle Rio Grande Basin (MRGB) are similar isotopically, with $\delta^{37}Cl$ values ranging from +3.1 to +5.0 ‰, $\delta^{18}O$ values ranging from +0.6 to +3.8 ‰, and $\Delta^{17}O$ values ranging from +0.3 to +1.3 ‰.

These data indicate that ClO_4^- from the SHP and MRGB is distinguishable from both Chilean ClO_4^- and synthetic ClO_4^- when all relevant stable isotope ratios are considered.

- Natural ClO_4^- samples from caliche deposits in and around Death Valley, California have lower $\delta^{37}Cl$ values (-0.8 to -3.7 ‰) and much higher $\Delta^{17}O$ values (+ 8.6 to +18.4 ‰) compared to the SHP and MRGB samples. Interestingly, however, all of the SHP, MRGB, and Death Valley samples analyzed to date are characterized by substantially elevated $^{36}Cl/Cl$ values (3130×10^{-15} to $28{,}800 \times 10^{-15}$) compared to those of synthetic or Chilean ClO_4^-. Overall, the SHP, MRGB, and Death Valley samples can be considered together as U.S. indigenous sources and, even though there are substantial ranges in the individual isotope ratios, this indigenous grouping is isotopically distinct from synthetic and Chilean ClO_4^- when all relevant isotope ratios are considered.

4. Experiments to date indicate that post depositional modification by biodegradation causes a reproducible fractionation factor ratio between O and Cl isotopes in ClO_4^- ($\varepsilon^{18}O/\varepsilon^{37}Cl = 2.5$) that is roughly perpendicular to the area in which mixtures of synthetic and Chilean ClO_4^- plot in dual isotope plots. Thus, biodegradation will not obscure differences between these two major sources, when considered with the large differences in $^{36}Cl/Cl$ and(or) $\Delta^{17}O$ values (which will not change appreciably during biodegradation). Biodegradation is also unlikely to lead to lead to errors in source delineation among indigenous U.S. sources and synthetic or Chilean sources of ClO_4^- when all relevant parameters are considered.

5. In addition to Cl and O isotopes of ClO_4^-, there are a large number of supporting methods/analyses available as forensic lines of evidence to help identify sources of ClO_4^- (or other contaminants) in a groundwater environment. These analyses include basic field parameters, stable H, O, N, and S isotopes in H_2O, NO_3^-, and

SO_4^{2-}, concentrations of anions, dissolved gases, and trace elements, and groundwater-age dating. The use of these methods in conjunction with Cl and O isotopic analyses of ClO_4^- is recommended in studies to identify the origin of ClO_4^- in groundwater.

6. The currently defined ranges of isotopic compositions characteristic of different ClO_4^- sources may evolve as more samples are analyzed, but these data already have proven useful for identifying perchlorate sources in a number of groundwater studies and we expect additional data will enhance the value of this approach for ClO_4^- forensic applications.

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** Commercial analysis of Cl and O isotopes in ClO_4^- is conducted by EIGL under the supervision of Dr. Neil Sturchio. To our knowledge, no other facilities currently offer this analysis on a commercial basis.*

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Appendix A: Stable Isotope Data for Perchlorate Sources

TABLE A-1. CHLORINE AND OXYGEN ISOTOPIC COMPOSITIONS OF PERCHLORATE SOURCE SAMPLES

Sample Identification	ClO_4 Salt	Sample Description	$\delta^{37}Cl$ (‰)	$\delta^{18}O$ (‰)	$\Delta^{17}O$ (‰)
SYNTHETIC					
Laboratory Reagents	$NaClO_4$	Mallinckrodt lot # 1190KHJJ[1]	+1.2	-16.2	+0.01
	$KClO_4$	Baker Analyzed lot # 45155[1]	+1.1	-24.8	+0.01
	$NaClO_4.H_2O$	Aldrich lot # 00722CG[1]	+1.3	-16.1	+0.12
	$KClO_4$	Sigma lot # 60K3451[1]	+0.5	-16.3	n.a.[4]
	$NaClO_4$	Sigma lot # 111K1334[1]	+1.0	-17.6	n.a.
	$KClO_4$	Hummel-Croton[1]	+0.4	-12.5	n.a.
	$NaClO_4.H_2O$	EM lot # SX0693-2[1]	-3.1	-17.2	+0.08
	$KClO_4$	General Chem. Co. lot # 13[1]	+0.6	-19.1	+0.00
	$RbClO_4$	Aldrich lot # AN00625LZ[1]	+1.3	-16.4	+0.11
	$CsClO_4$	Aldrich lot # LI09119JI[1]	+1.6	-16.6	-0.04
	$CsClO_4$	Aldrich lot # 02407AS[1]	+0.6	-16.9	+0.00
	$HClO_4$	Baker 9656-1, lot # 146358[1]	n.a.	-14.6	+0.01
	$KClO_4$	Aldrich, lot # 11921HO[1]	+0.6	-17.0	+0.00
	$KClO_4$	Allied Chemicals[2]	n.a.	-19.9	-0.06
	$KClO_4$	Aldrich[2]	n.a.	-17.8	-0.12
	$NaClO_4$	EM-Science[2]	n.a.	-17.3	-0.06
	$NaClO_4$	Fisher Scientific[2]	n.a.	-19.5	-0.20
	$AgClO_4$	Aldrich[2]	n.a.	-17.3	-0.10
Manufactured ClO_4^-	$NaClO_4$	American Pacific Co. (N3300401) [1]	+0.4	-22.3	-0.01
	$KClO_4$	American Pacific Co. (P0900402) [1]	+0.4	-21.5	+0.07
	NH_4ClO_4	American Pacific Co. (A2000433) [1]	+0.4	-21.3	n.a.
	$NaClO_3$	Western Electrochemical Co. (TO403E) [1]	+1.1	n.a.	+0.06
	$NaClO_4$	Western Electrochemical Co. (TO403B) [1]	+0.9	-20.4	+0.00
NATURAL					
Chilean ClO_4^-	$KClO_4$	Commercial Hoffman fertilizer[1]	-13.7	-8.4	+8.95
	$CsClO_4$	Commercial Hoffman fertilizer[1]	-14.5	-9.3	+8.93
	$CsClO_4$	Atacama, Chile evaporite (AT-74-1) [1]	-11.8	-4.2	+9.57
	$CsClO_4$	SQM-7791 fertilizer (RSIL N7791) [1]	-14.2	-7.6	+9.25
	$CsClO_4$	Atacama (AT-24-1) [2]	n.a.	-4.6	+9.6
	$CsClO_4$	Atacama (AT-74-1) [2]	n.a.	-4.5	+9.6

	$KClO_4$	Atacama (AT-75-1) [2]	n.a.	-24.8	+4.2
	$CsClO_4$	Commercial Hoffman fertilizer[2]	n.a.	-9.0	+8.8
Chilean *ClO_4 (Con't)*	$CsClO_4$	Atacama – well water[3]	-12.9	-7.6	+9.3
	$CsClO_4$	P1[3]	-14.3	-10.5	+8.1
	$CsClO_4$	P2[3]	-13.6	-6.7	+9.2
	$CsClO_4$	P3[3]	-11.8	-5.7	+8.8
	$CsClO_4$	P4[3]	n.a.	-7.8	+8.5
	$CsClO_4$	GJ01[3]	-12.5	-5.2	+9.4
	$CsClO_4$	J-470[3]	-12.5	-5.6	+8.8
Southern High Plains Groundwater	$CsClO_4$	Well - MW2A[3]	+4.2	+1.0	+0.3
	$CsClO_4$	Well - MW2B[3]	+3.7	+1.4	+0.3
	$NaClO_4$	Well - MW3A[3]	+5.0	+2.2	+0.3
	$CsClO_4$	Well - MW3B[3]	+4.1	+2.4	+0.3
	$CsClO_4$	Well - GW2[3]	+5.0	+3.8	+0.2
	$CsClO_4$	Well - BW2[3]	+4.5	+0.6	+0.6
	$NaClO_4$	Well - JTY1[3]	+5.1	+2.7	+0.5
	$HClO_4$	Well - KJ1[3]	+4.5	+4.8	+0.8
	$CsClO_4$	Well - RR-8[3]	+3.1	+1.5	+1.2
	$CsClO_4$	Well - RR 16[3]	+3.6	+1.9	+1.3
	$CsClO_4$	Well TTU-G1S[1]	+6.2	+4.7	+0.4
	$CsClO_4$	Well TTU-M3L[1]	+5.1	+2.5	+0.5
Southern High Plains Vadose Zone		SHP-V[3]	+3.7	+2.1	+0.8
Death Valley Caliche	$CsClO_4$	Confidence Hills 1[3]	-0.8	+2.9	+8.6
	$CsClO_4$	Confidence Hills 2[3]	-3.8	+7.2	+12.8
	$CsClO_4$	Saratoga Hills[3]	-1.4	+6.4	+10.9
	$CsClO_4$	Zabriskie[3]	-3.7	+26.1	+18.4

[1] Data from Sturchio et al., (2006).
[2] Data from Bao and Gu, (2004).
[3] Data from Jackson et al., (2010).
[4] n.a. - data "not available".

Appendix B: Occurrence and Potential Sources of Perchlorate Releases to the Environment as of April, 2003 (Mayer, 2003)

OCCURRENCE AND POTENTIAL SOURCES OF PERCHLORATE RELEASES TO THE ENVIRONMENT as of APRIL, 2003. [a]

State	Location	Suspected Source	Type of Contamination	Max. Conc. ppb
AL	Redstone Army Arsenal - NASA Marshall Space Flight Huntsville, AL	Propellant Manufacturing, Testing, Research, Disposal	Monitoring Well Springs/Seeps	19,000 37
AL	Unregulated Contaminant Monitoring Rule (UCMR) data Escambia County, AL	Unknown	Public Water Supply	8.9
AZ	Apache Nitrogen Products Benson, AZ	Explosives Manufacturing	Monitoring Well	670
AZ	Aerodyne Gila River Ind. Res., Chandler, AZ	Propellant Testing	Monitoring Well	18
AZ	Davis Monthan AFB Tucson, AZ	Explosives/ Propellant Disposal	Soil	--
AZ	Unidynamics Phoenix Inc. Phoenix Goodyear Airport Goodyear, AZ	Explosives/Ordnance Manufacturing	Public Water Supply Well Monitoring Well	65 80
AZ	Unidynamics Phoenix Inc. White Tanks Disposal Area Maricopa County, AZ	Explosives/ Ordnance Disposal	Soil	--
AZ	Universal Propulsion Phoenix, AZ	Rocket Manufacturing	Soil	--
AR	Atlantic Research East Camden, AR	Rocket Manufacturing Disposal - Open burn/ Open detonation	Monitoring Well Surface Water Soil	640,000 12,500 --
CA	Aerojet General Rancho Cordova, CA	Rocket Manufacturing	Public Water Supply Well Monitoring Well	260 640,000
CA	Alpha Explosives Lincoln, CA	Explosives Manufacturing	Monitoring Well Reported in Surface Water	67,000
CA	Boeing/ Rocketdyne, NASA at Santa Susana Field Lab USDOE Santa Susana, CA	Rocket Research, Testing and Production	Monitoring Well	750
CA	Casmalia Resources Casmalia, CA	Hazardous Waste Management Facility	Monitoring Well	58
CA	El Toro Marine Corps Air Station Orange County, CA	Explosives Disposal	Monitoring Well	380
CA	Edwards AFB Jet Propulsion Lab, North Base Edwards, CA	Rocket Research	Monitoring Well	300

(a) - Information from Mayer (2003). All reports have been confirmed by federal, state or county. Soil concentrations are not listed.

OCCURRENCE AND POTENTIAL SOURCES OF PERCHLORATE RELEASES TO THE ENVIRONMENT as of APRIL, 2003. [a]

State	Location	Suspected Source	Type of Contamination	Max. Conc ppb
CA	Lawrence Livermore National Laboratory Site 300 Tracy, CA	U.S. Dept. of Energy Explosives Research	Monitoring Well	84
CA	Lockheed Propulsion Upper Santa Ana Valley Redlands, CA	Rocket Manufacturing	Public Water Supply Well	87
CA	NASA - Jet Propulsion Lab Pasadena, CA	Rocket Research	Public Water Supply Well	54
CA	Olin Safety Flare Morgan Hill, CA	Flare Manufacturing	Public Water Supply Well Monitoring Well	15 167
CA	Rancho Cordova Test Site (Affects Mather AFB) Rancho Cordova, CA	Boeing/ McDonnell Douglas Rocket Testing	Public Water Supply Well Monitoring Well	120 1800
CA	Rialto-Colton Plume Rialto, CA	Fireworks Facility Flare Manufacturing Rocket Research and Manufacturing	Public Water Supply Well	811
CA	San Fernando Valley Glendale, CA	Grand Central Rocket ? Rocket Manufacturing	Monitoring Well	13
CA	San Gabriel Valley Baldwin Park, CA	Aerojet Rocket Manufacturing	Public Water Supply Well Monitoring Well	159 2,180
CA	San Nicholas Island Ventura County, CA	U.S. Navy Firing Range	Public Water Supply (Springs)	12
CA	Stringfellow Superfund Site Glen Avon, CA	Hazardous Waste Disposal Facility	Monitoring Well Private Well	682,000 37
CA	UTC (United Technologies) San Jose, CA	Rocket Testing	Monitoring Well	180,000
CA	Whittaker-Bermite Ordnance Santa Clarita, CA	Ordnance Manufacturing	Public Water Supply Well	47
CA	Whittaker Ordinance Hollister, CA	Ordnance Manufacturing	Private Well Monitoring Well	810 88
CO	Pueblo Chemical Depot Pueblo, CO	Munition Demobilizing Open burn/ Open detonation	Monitoring Well	180
GA	Unregulated Contaminant Monitoring Rule (UCMR) data Houston County, GA	Unknown	Public Water Supply	5.2
GA	Unregulated Contaminant Monitoring Rule (UCMR) data Oconee County, GA	Unknown	Public Water Supply	38

(a) - Information from Mayer (2003). All reports have been confirmed by federal, state or county. Soil concentrations are not listed.

OCCURRENCE AND POTENTIAL SOURCES OF PERCHLORATE RELEASES TO THE ENVIRONMENT as of APRIL, 2003 [a]

State	Location	Suspected Source	Type of Contamination	Max. Conc. ppb
IA	Ewart, IA	Unknown source	Livestock Well	29
IA	Hills, IA	Unknown source	Private Well	30
IA	Iowa Army Ammunition Plant Middleton, IA	Propellant handling	Monitoring Well	9
IA	Napier, IA	Agriculture(?)	Private Well	11
KS	Herington, KS	Ammunition Facility	Monitoring Well	9
MD	Aberdeen Proving Grounds Aberdeen, MD	Field Training - Pyrotechnics and Explosives	Public Water Supply Well Monitoring Well/ Hydropunch	5 24
MD	Naval Surface Warfare Center Indian Head, MD	Propellant Handling	Waste Discharge to Surface Water	>1,000
MD	White Oak Fed. Research Center (Naval Surface Warfare Center) White Oak, MD	Propellant Handling	Monitoring Well/ Hydropunch	798
MD	Unregulated Contaminant Monitoring Rule (UCMR) data Hagerstown, MD	Unknown	Public Water Supply	4
MA	Massachusetts Military Res. Barnstable County, MA	Disposal - Open burn/ Open detonation	Monitoring Well	100
MN	Unregulated Contaminant Monitoring Rule (UCMR) data New Brighton, MN	Unknown	Public Water Supply	4.5
MN	Unregulated Contaminant Monitoring Rule (UCMR) data Northfield, MN	Unknown	Public Water Supply	6
MO	ICI Explosives Joplin, MO	Explosives Facility	Monitoring Well	107,000
MO	Lake City Army Amm. Plant Independence, MO	Propellant Handling	Monitoring Well	70
NE	Lewiston, NE	Agricultural Chemical Facility	Shallow Private Well	5
NE	Mead, NE	Fireworks Facility	Monitoring Well	24
NV	Boeing/Rocketdyne near Reno, NV	Propellant Testing	Monitoring Well	400
NV	Kerr-McGee/BMI Henderson, NV	Perchlorate Manufacturing	Public Water Supply Monitoring Well Surface Water	24 3,700,000 120,000
NV	PEPCON Henderson, NV	Perchlorate Manufacturing	Monitoring Well	600,000

(a) - Information from Mayer (2003). All reports have been confirmed by federal, state or county. Soil concentrations are not listed.

OCCURRENCE AND POTENTIAL SOURCES OF PERCHLORATE RELEASES TO THE ENVIRONMENT as of APRIL, 2003. [a]

State	Location	Suspected Source	Type of Contamination	Max. Conc. ppb
NJ	Unregulated Contaminant Monitoring Rule (UCMR) data Middlesex County, NJ	Unknown	Public Water Supply	7
NJ	Picatinny Arsenal Morris County, NJ	Munitions Handling	Monitoring Well	627
NM	Cannon AFB Clovis, NM	Explosives Disposal	Public Water Supply	46
NM	New Mexico American Water Co Clovis, NM	Unknown	Public Water Supply Well	5.8
NM	Deming, NM	Agricultural	Public Water Supply Well	20
NM	Des Moines, NM	Agricultural	Public Water Supply Well	4.5
NM	Fort Wingate Depot Activity Gallup, NM	Explosives Disposal	Monitoring Well Soil	2,860 --
NM	Holloman AFB Alamogordo, NM	Rocket Testing	Monitoring Well Seasonal Surface Water Soil	40 16,000 --
NM	Los Alamos National Lab Los Alamos, NM	U.S. Dept of Energy Lab Chemicals	Public Water Supply Well Monitoring Well Deep Borehole Water	3 220 1,662
NM	Melrose Air Force Range Melrose, NM	Explosives	Public Water Supply Well	40.7
NM	Mountain View Albuquerque South Valley, NM	Agricultural	Public Water Supply Well	4.8
NM	White Sands Missile Range White Sands, NM	Rocket Testing	Monitoring Well Soil	21,000 --
NY	Unregulated Contaminant Monitoring Rule (UCMR) data Bethpage, NY	Unknown	Public Water Supply	5
NY	Unregulated Contaminant Monitoring Rule (UCMR) data Plainview, NY	Unknown	Public Water Supply	11
NY	Westhampton Suffolk County, NY	Unknown Source(s), Possibly Agricultural	Public Water Supply Well Monitoring Well	16 3,370
NY	Yaphank Suffolk County, NY	Fireworks	Private Well Monitoring Well	26 122
NC	Unregulated Contaminant Monitoring Rule (UCMR) data Nash County, NC	Unknown	Public Water Supply	5.8
OR	Umatilla Army Depot, Ammunition Demolition Activity Hermiston, OR	Munitions Disposal OB/OD	Monitoring Well	10

(a) - Information from Mayer (2003). All reports have been confirmed by federal, state or county. Soil concentrations are not listed.

OCCURRENCE AND POTENTIAL SOURCES OF PERCHLORATE RELEASES TO THE ENVIRONMENT as of APRIL, 2003. [a]

State	Location	Suspected Source	Type of Contamination	Max. Conc. ppb
OR	Elf Atochem Portland, OR	Perchlorate Manufacturing	Monitoring Well	1000
PA	Unregulated Contaminant Monitoring Rule (UCMR) data Berks County, PA	Unknown	Public Water Supply	4
PA	Unregulated Contaminant Monitoring Rule (UCMR) data Crawford County, PA	Unknown	Public Water Supply	33
PA	Unregulated Contaminant Monitoring Rule (UCMR) data Huntingdon County, PA	Unknown	Public Water Supply	6.7
PA	Unregulated Contaminant Monitoring Rule (UCMR) data Lancaster County, PA	Unknown	Public Water Supply	12
TX	Andrews County, TX	Unknown Source(s)	Public Water Supply Well	15.8
TX	Dawson County, TX	Unknown Source(s)	Public Water Supply Well Private Well	26 58.8
TX	Ector County, TX	Unknown Source(s)	Public Water Supply Well	5
TX	Gaines County, TX	Unknown Source(s)	Public Water Supply Well Private Well	27 30
TX	Glasscock County, TX	Unknown Source(s)	Public Water Supply Well Private Well	1.1* 3* *estimated
TX	Howard County, TX	Unknown Source(s)	Public Water Supply Well Private Well	1.4* 26 *estimated
TX	Unregulated Contaminant Monitoring Rule (UCMR) data Kleburg County, TX	Unknown Source	Public Water Supply Well	4.5
TX	Unregulated Contaminant Monitoring Rule (UCMR) data Hockley County, TX	(s)Improper Cathodic Protection	Elevated Storage Tank	32
TX	Lone Star Army Ammunition Plant Texarkana, TX	Propellant and Munitions Handling	Monitoring Well Surface Water Soil	23 6 --
TX	Longhorn Army Ammunition Depot Karnak, TX	Propellant Handling	Monitoring Well Reported in Surface Water Soil	169,000 -- --
TX	Martin County, TX	Unknown Source(s)	Public Water Supply Well Private Well	32 19.1

(a) - Information from Mayer (2003). All reports have been confirmed by federal, state or county. Soil concentrations are not listed.

OCCURRENCE AND POTENTIAL SOURCES OF PERCHLORATE RELEASES TO THE ENVIRONMENT as of APRIL, 2003. [a]

State	Location	Suspected Source	Type of Contamination	Max. Conc. ppb
TX	McGregor Naval Weapons Plant McGregor, TX	Propellant Handling	Monitoring Well Reported in Surface Water Soil	91,000 – --
TX	Midland County, TX	Unknown Source(s)	Public Water Supply Well	46
TX	PANTEX Plant (USDOE) Amarillo, TX	Explosives	Monitoring Well	340
TX	Red River Army Depot Texarkana, TX	Propellant Handling	Monitoring Well	80
UT	Alliant Tech Systems Magna, UT	Rocket Manufacturing	Public Water Supply Well	16
UT	Thiokol Promontory, UT	Rocket Manufacturing	Water Supply Well (Inactive)	42
VA	Unregulated Contaminant Monitoring Rule (UCMR) data Accomack County, VA	Unknown	Public Water Supply	4.3
WA	Camp Bonneville near Vancouver, WA	Explosives/Propellant OB/OD Disposal	Monitoring Wells	200
WA	Unregulated Contaminant Monitoring Rule (UCMR) data Lakewood, Pierce County, WA	Unknown	Public Water Supply	6
WA	Unregulated Contaminant Monitoring Rule (UCMR) data Puyallup, Pierce County, WA	Unknown	Public Water Supply	8
WV	Allegheny Ballistics Lab Rocket Center, WV	Rocket Research, Production, OB/OD	Surface Discharge of Groundwater Extraction	400

(a) - Information from Mayer (2003). All reports have been confirmed by federal, state or county. Soil concentrations are not listed.

APPENDIX C

Environmental Isotope Geochemistry Laboratory CSIA Sampling Protocol

Environmental Isotope Geochemistry Laboratory
Instructions for Perchlorate Collection Field Columns

DO NOT OPEN THE COLUMNS. Pre filtration of water is necessary. Non-reactive, non-activated filter media is required. Acceptable examples:

- Groundwater filter cartridges, 5 micron (Millipore)
- Filter-Bag, polyester or polypropylene (McMaster Carr)
- Whole house water filter with **sediment filter element** NOT odor or contaminant filters (Home Depot or Lowes)

Connect pre-filter to column inlet using 8”-10” flexible tubing. Attach the sampling apparatus to a pump, observing flow direction and column number assignment, and control the flow to the optimal rate of 0.5-2.0 liters per minute per column

Column flow rates may decrease with time. If the pre-filter becomes clogged and reduces the flow through the column, detach the pre-filter and install a new one. Do not attempt to use the column without the pre-filter or to modify the column.

The amount of resin in the sampling apparatus is optimized for the recovery of ~**10 milligrams of perchlorate** under appropriate flow conditions.

Example: For a sample concentration of 10 ppb perchlorate, the **minimum** total volume of water required is 1,000 liters (264 gallons), requiring at least 8.3 to 33.2 hours of flow.

Note: please record **column ID #s** with all sample identification.

After at least the minimum amount of sample volume required has passed through the column to collect 10 mg perchlorate (more is better if time allows), detach the apparatus from the pump, remove and discard the pre-filter and connect the tubing from the column inlet to the column outlet effectively sealing the column. Keep columns on ice packs after sampling, but do not freeze. Return, with Submission Worksheet and Chain of Custody forms in supplied cooler with ice pack to:

andrew.jackson@ttu.edu

Andrew Jackson.
Civil and Environmental Engineering
Texas Tech University
911 Boston
Box 41023
Lubbock, TX 79409-1023

806-834-6575

Perchlorate Sample Submission Worksheet

To be submitted with resin column to laboratory **in addition** to any other chain of custody forms

Please supply as much information as possible, attach water analysis results if available, attach additional pages if necessary.

Sample ID	Column # (imprinted on column)	Date	Concentration of perchlorate in water source	Duration of sampling	Flow rate	Estimated perchlorate on column	Sample description	List other compounds known to be in water	Any additional sample descriptors
ie. WELL-#123	*###*	*1/1/2001*	*10 µg/L*	*48hrs*	*1L/min*	*(ug/L) (L/min) (hrs)(60min/hr)*	*ie: "municipal water"*	*ie: dissolved Cr, conc unknown*	*ie: high tannins*

Additonal comments:

Environmental Isotope Geochemistry Laboratory
Geological Sciences Department
University of Delaware

221 Academy St, ISE lab 458, Newark DE 19716
lab (302)831-8022, fax (302)831-4158
lheraty@udel.edu, sturchio@udel.edu

CHAIN OF CUSTODY

Project:
Location:

Send to Primary Contact:
Company:
Address:
Phone:
email:

Report to :
Company:
Address:
Phone:
email:

Prepared/ Sampled by:

Date:

page _____ of _____

	Sample ID:	Other ID info:	Description:	Purpose/Comments:	EIGL ID:
1					
2					
3					
4					
5					
6					
7					
8					
9					
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30					

Relinquished By:	Date: Time	Received By:	Date: Time
Relinquished By:	Date: Time	Received By:	Date: Time

APPENDIX D
Health And Safety Plan

Geosyntec consultants

engineers | scientists | innovators

HEALTH AND SAFETY PLAN

Shieldalloy Metallurgical Corporation Superfund Site
Operable Unit 3 Perchlorates
Newfield, New Jersey

Prepared for

Shieldalloy Metallurgical Corporation
35 South West Boulevard
Newfield, NJ 08344

Prepared by

Geosyntec Consultants, Inc.
7 Graphics Drive, Suite 106
Ewing, NJ 08628

Project JR0241

May 2019

TABLE OF CONTENTS

HEALTH AND SAFETY INCIDENT RESPONSE PROCEDURES IV

ROUTE TO HOSPITAL V

ROUTE TO URGENT CARE FACILITY VI

SITE MAP VII

OFF-SITE MAP VIII

1. INTRODUCTION 1

2. SIGNATURES 2
   - 2.1 Preparers and Reviewers 2
   - 2.2 Site Workers 2

3. EMERGENCY CONTACT INFORMATION 4

4. APPLICABILITY OF THIS HASP 5

5. SITE/TASK/HAZARD DESCRIPTION 6
   - 5.1 Site Background 6
   - 5.2 Task Descriptions 6
   - 5.3 Chemical Hazards 7
   - 5.4 Physical Hazards 7
   - 5.5 Biological Hazards 7

6. GENERAL SAFE WORK PRACTICES 9

7. EMERGENCY RESPONSE 10
   - 7.1 Injury and Emergency Response Procedures 10
   - 7.2 Emergency Response Equipment 10

8. KEY PERSONNEL AND HEALTH AND SAFETY RESPONSIBILITIES 11

9. WORKER TRAINING AND MEDICAL SURVEILLANCE 13
   - 9.1 Pre-Assignment and Annual Refresher Training 13
   - 9.2 Site Supervisor Training 13
   - 9.3 Initial Site Safety Orientation and HASP Review 13
   - 9.4 Baseline Medical Surveillance Exam 14

9.5 Periodic/Annual/Biennial Medical Exam 14
9.6 Exposure/Activity/Project-Specific Medical Testing 14
9.7 Exit Exam 14

10. MAPS AND SITE CONTROL 15
10.1 Routes to Hospital and Urgent Care Facility 15
10.2 Site Maps 15
10.3 Buddy System 15
10.4 Controlled Work Zones 15
10.5 Site Access 16
10.6 Inspections 16

11. TAILGATE MEETINGS 17

12. STOP WORK AUTHORITY 18

13. AIR MONITORING 19

14. PERSONAL PROTECTIVE EQUIPMENT 20

15. DECONTAMINATION 21

16. SPILL CONTAINMENT 22

17. CONFINED SPACE ENTRY 24

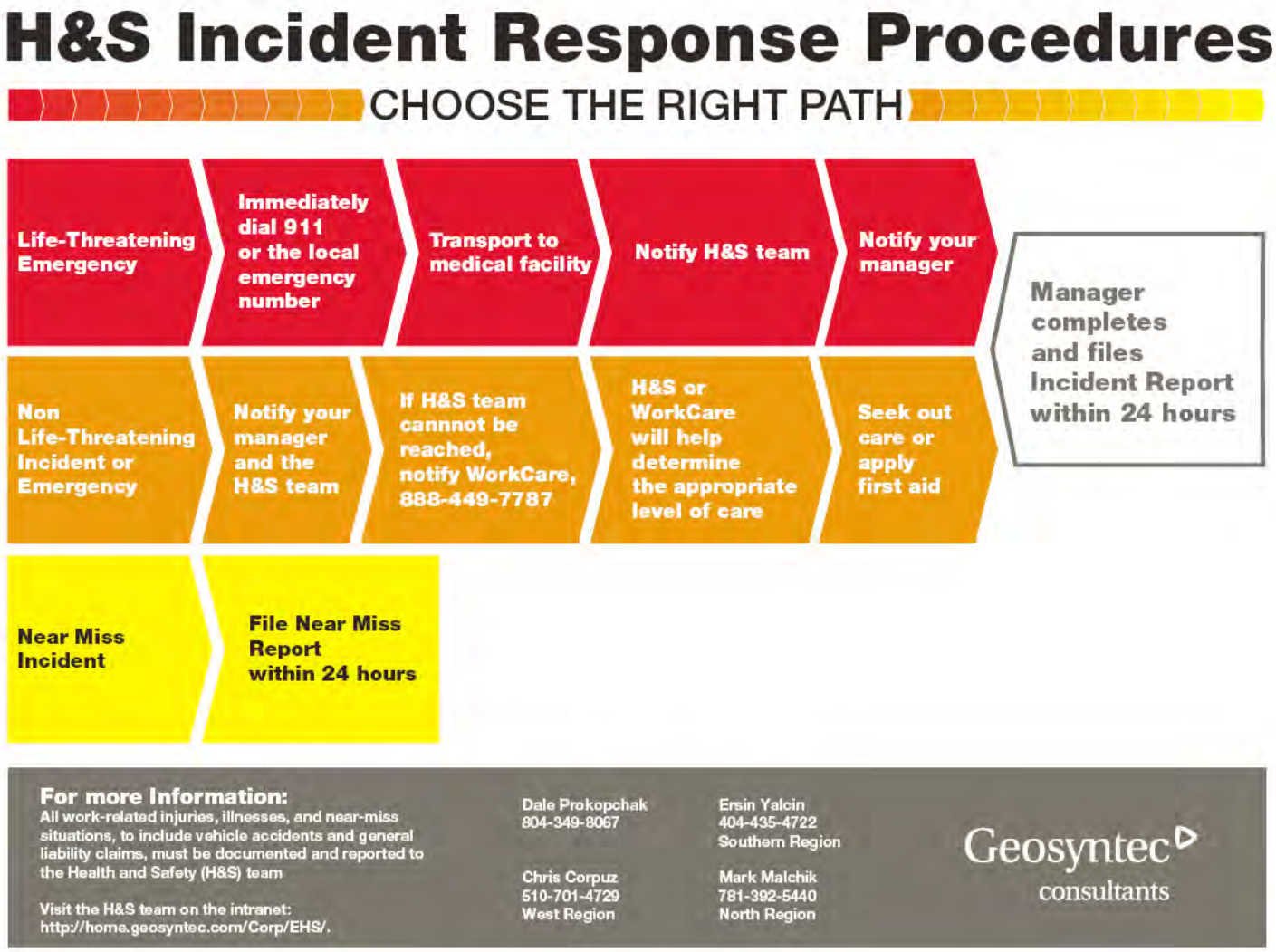
18. GLOBALLY-HARMONIZED SYSTEM FOR HAZARD COMMUNICATION 25

19. HASP AMENDMENTS 26

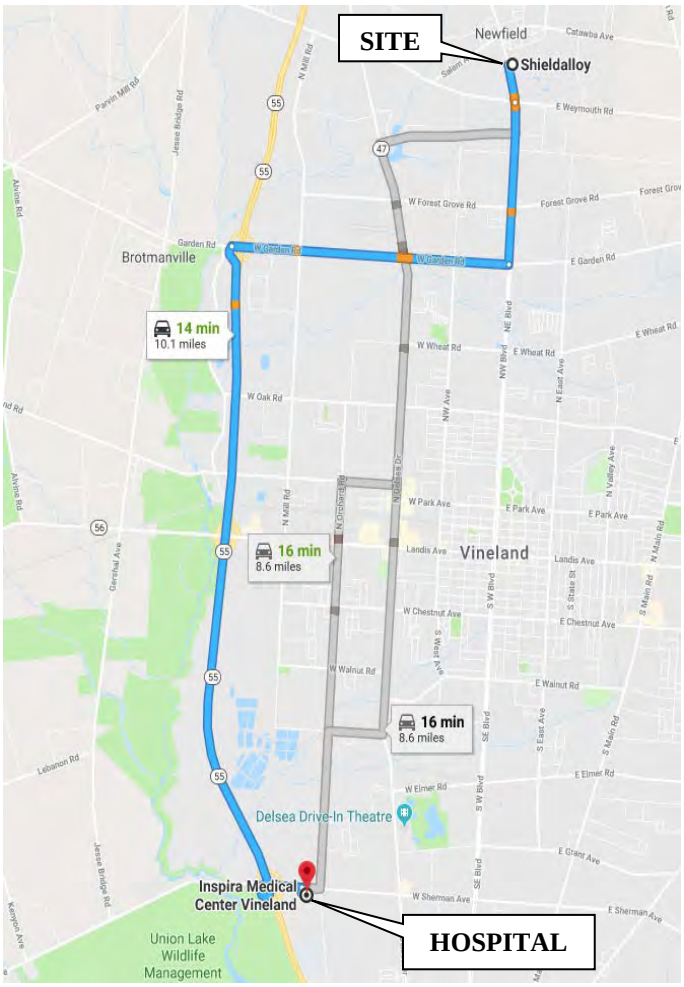
LIST OF APPENDICES

Appendix A: HASP Amendments
Appendix B: Task Hazard Analyses
Appendix C: Summary of Chemical Hazards
Appendix D: Air Monitoring
Appendix E: Personal Protective Equipment
Appendix F: Safety Data Sheets
Appendix G: COVID-19 Prevention Measures

HEALTH AND SAFETY INCIDENT RESPONSE PROCEDURES



ROUTE TO HOSPITAL



Shieldalloy
35 West Blvd, Newfield, NJ 08344

Drive from W Garden Rd and NJ-55 S to Vineland

13 min (10.0 mi)

1. Head south on West Blvd toward W Weymouth Rd — 0.3 mi
2. Continue onto NW Blvd — 1.3 mi
3. Turn right onto W Garden Rd — 2.5 mi
4. Turn left to merge onto NJ-55 S — 5.3 mi
5. Take exit 29 for County 552 toward Bridgeton/S Vineland — 0.2 mi
6. Turn right onto W Sherman Ave (signs for County Road 552 E) — 0.4 mi

Drive to your destination

29 s (0.1 mi)

7. Turn right — 217 ft
8. Turn left
   Destination will be on the right — 285 ft

Inspira Medical Center Vineland

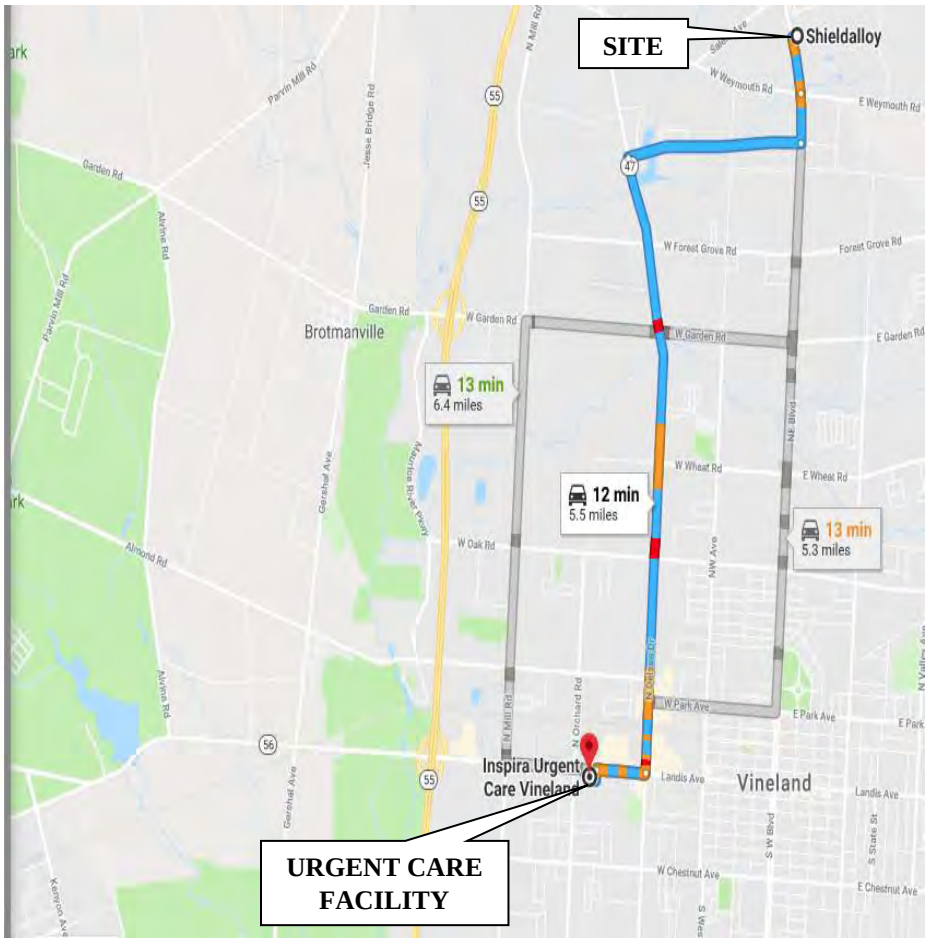
Inspira Medical Center Vineland
10.1 miles, 14 minutes
(856) 641-8000
1505 W Sherman Ave
Vineland, NJ 08360

ROUTE TO URGENT CARE FACILITY

Shieldalloy
35 West Blvd, Newfield, NJ 08344

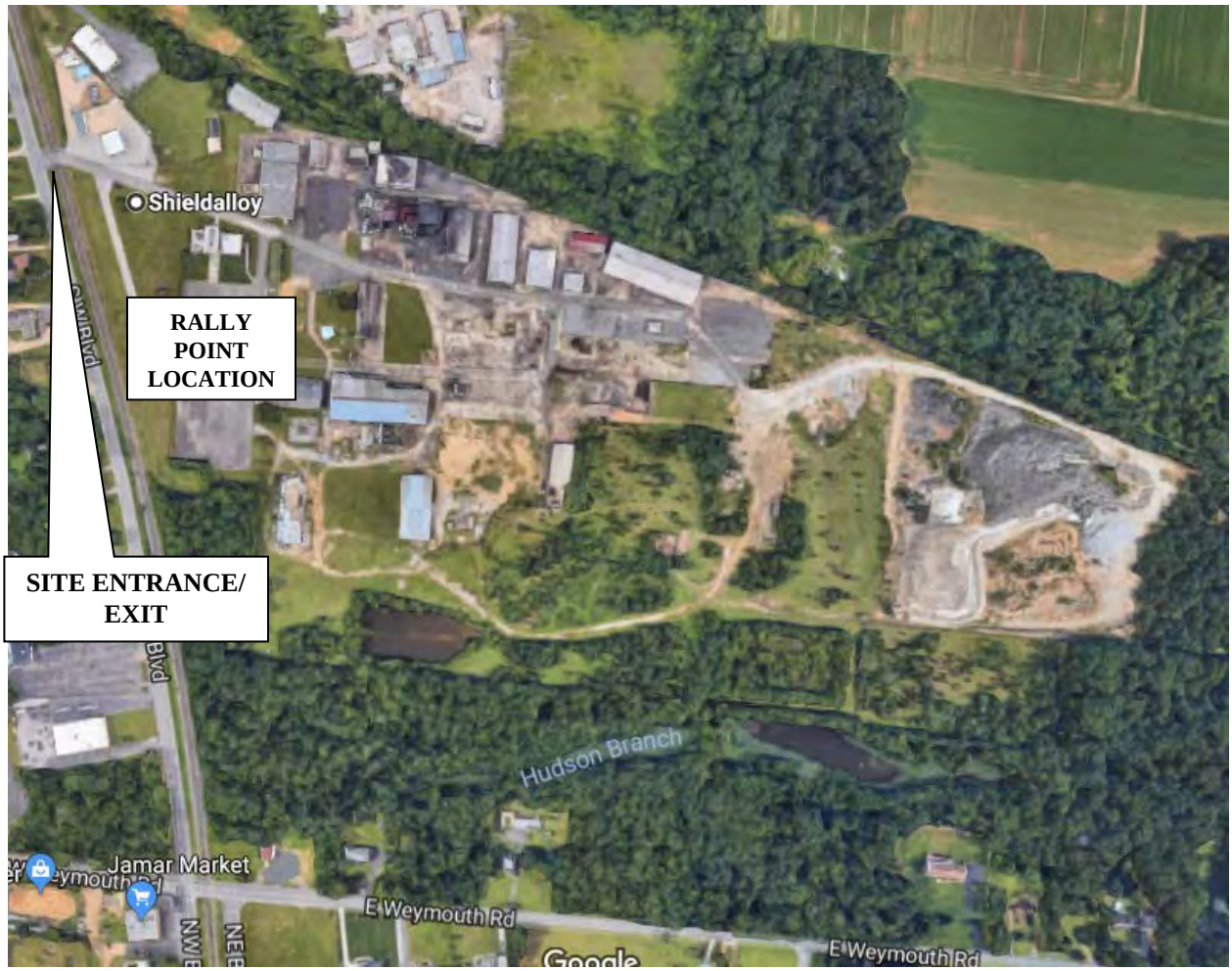
- Take West Blvd to W Arbor Ave in Vineland
  - 1 min (0.6 mi)
  - Head south on West Blvd toward W Weymouth Rd
  - 0.3 mi
  - Continue onto NW Blvd
  - 0.3 mi
- Turn right onto W Arbor Ave
  - 2 min (1.2 mi)
- Follow N Delsea Dr
  - 7 min (3.6 mi)
  - Turn left onto N Delsea Dr
  - 3.3 mi
  - Turn right onto W Landis Ave
  - 0.3 mi
- Drive to your destination
  - 42 s (0.1 mi)

Inspira Urgent Care Vineland
1297 W Landis Ave, Vineland, NJ 08360



Inspira Urgent Care
5.5 miles, 12 minutes
(856) 507-8548
1297 W Landis Ave
Vineland, NJ 08360

SITE MAP

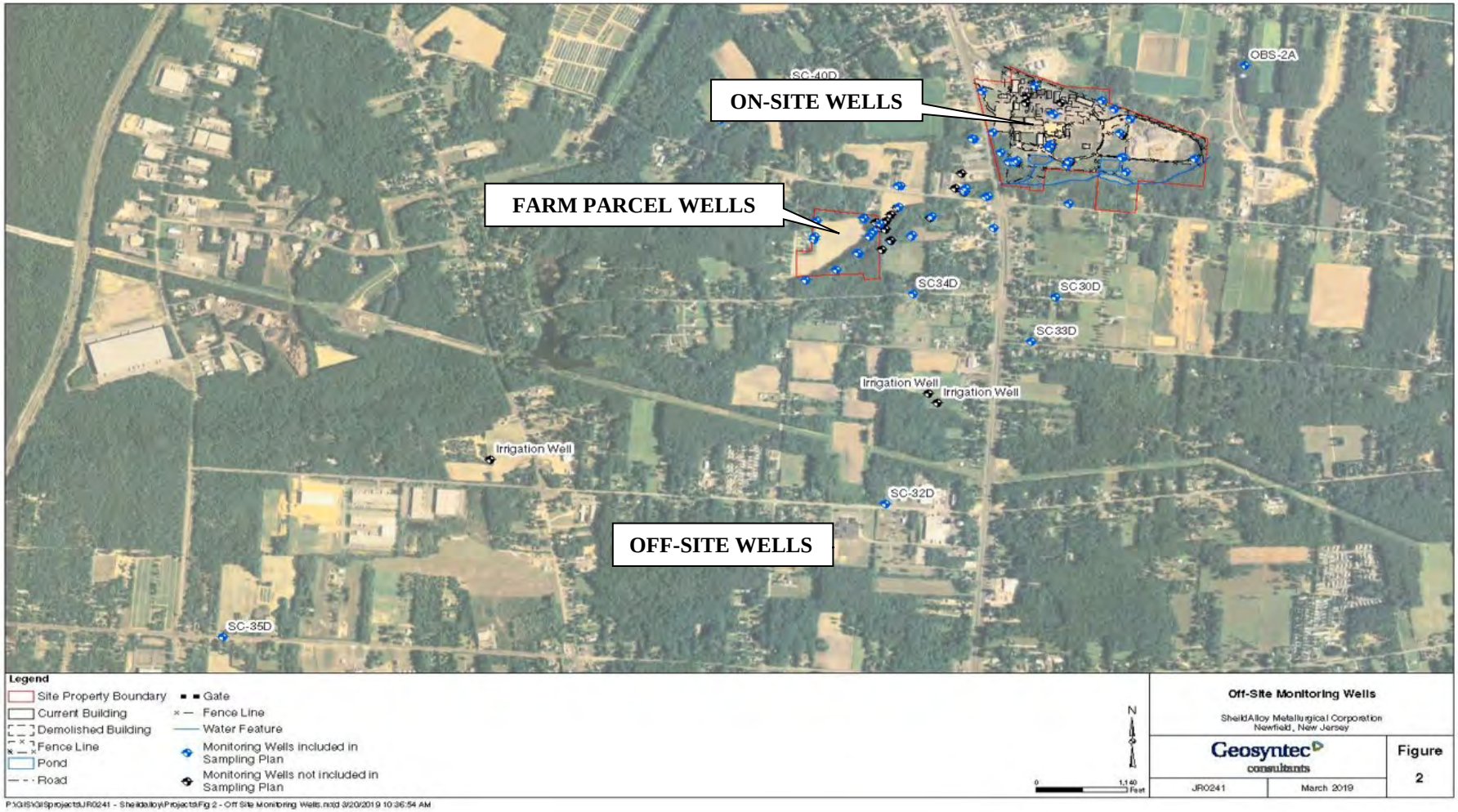


Site Address:

35 South West Boulevard

Newfield, NJ 08344

OFF-SITE MAP


ON-SITE WELLS
FARM PARCEL WELLS
OFF-SITE WELLS
OBS-2A
SC-40D
SC34D
SC30D
SC33D
Irrigation Well
Irrigation Well
Irrigation Well
SC-32D
SC-35D
Legend
Site Property Boundary
Current Building
Demolished Building
Fence Line
Pond
Road
Gate
Fence Line
Water Feature
Monitoring Wells included in Sampling Plan
Monitoring Wells not included in Sampling Plan
N
0
1,140
Feet
Off-Site Monitoring Wells
ShieldAlloy Metallurgical Corporation
Newfield, New Jersey
Geosyntec consultants
Figure
2
JR0241
March 2019
P:\GIS\GISprojects\JR0241 - Shieldalloy\Projects\Fig 2 - Off Site Monitoring Wells.mxd 3/20/2019 10:36:54 AM

1. INTRODUCTION

This Site-specific Health and Safety Plan (HASP) was prepared to address project-specific hazards known or suspected to be present associated with the existing conditions and work to be performed at Operable Unit (OU) 3 of the Shieldalloy Superfund Site in Newfield, New Jersey (the Site). This HASP was prepared to meet the requirements specified in Occupational Safety and Health (OSHA) Hazardous Waste Operations Emergency and Response (HAZWOPER) program, Geosyntec Consultants, Inc. (Geosyntec)'s Health and Safety (H&S) Procedure HS 301, and the H&S requirements of Shieldalloy Metallurgical Corporation (SMC).

2. SIGNATURES

2.1 Preparers and Reviewers

This HASP must be maintained on-Site when field work is being performed. The Site Health and Safety Officer (SHSO) can change or amend this document, in agreement with the Health and Safety Coordinator (HSC) or Project Manager (PM). Amendments (e.g., changes in personal protective equipment, addition of tasks, etc.) must be documented in Section **Error! Reference source not found.** and in Appendix A. This HASP must be reviewed and amended on an annual basis for projects lasting more than one year.

Prepared by:

SHSO	Date

Reviewed by:

HSC	Date

Approved by:

Project Manager	Date

This HASP has been given to the following H&S approved subcontractor(s).

Subcontractor	Representative	Date
Subcontractor	Representative	Date
Subcontractor	Representative	Date

2.2 Site Workers

This HASP must be reviewed by personnel prior to Site work. Workers not in attendance at the initial meeting must be trained by the SHSO on the information covered in the pre-entry briefing. After reading the HASP and attending a pre-entry briefing, Geosyntec employees and other parties covered under this HASP must sign the following acknowledgment statement.

"I have read, understand, and will perform my work in accordance with the information set forth in this HASP."

Signature	Printed Name	Date

3. EMERGENCY CONTACT INFORMATION

Contact	Telephone Numbers	
	Office	Alternate (Type)
Fire Department	(856) 697-4851	
Police Department	(856) 694-1415	
Site Emergency Response (if applicable)	911	
Hospital – Inspira Medical Center Vineland	(856) 641-8000	
Urgent Care – Inspira Urgent Care	(856) 507-8548	
Director of H&S – Dale Prokopchak	(804) 332-6376	(804) 349-8067 (Cell)
H&S Regional Manager – Mark Malchik	(978) 206-5777	(781) 392-5440 (Cell)
Project Manager – Seth Kellogg	(609) 493-9018	(732) 354-8463 (Cell)
Site Health & Safety Officer – Jessica Evans	(609) 493-9003	(609) 379-9685 (Cell)
H&S Coordinator – Matt Mraw	(609) 493-9004	(609) 462-1198 (Cell)
Principal- or Associate-in-Charge – John Persico	(609) 493-9008	(609) 903-6227 (Cell)
Utility Emergencies	811	
Work Care	(888) 449-7787	(714) 978-7488
Facility Contact – John Hunt	(484) 582-3519	(617) 957-5961 (Cell)
Client Contact – John Hunt	(484) 582-3519	(617) 957-5961 (Cell)
Laboratory Contact – Liz Bauer	(717) 556-7290	

4. APPLICABILITY OF THIS HASP

This HASP was prepared in accordance with Geosyntec's H&S Procedures for use by Geosyntec project staff and subcontractors. Subcontractors, at a minimum, shall ensure that their employees, and those of its lower tier subcontractors, comply with these procedures and other health, safety and security provisions in the Subcontract. Compliance with this HASP shall represent the minimum requirements to be met by subcontractors, who shall be responsible for examining all requirements and determining whether additional or more stringent health, safety and security provisions are appropriate for their portion of the work and implementing them accordingly. Therefore, for firms executing all or any portion of the work, this document and its contents should not be used without a thorough peer review by their health and safety managers. Prior to commencing work, such firms are responsible for reviewing and supplementing the HASP to add appropriate procedures specific to their portion of the work.

5. SITE/TASK/HAZARD DESCRIPTION

5.1 Site Background

The manufacturing portion of the SMC facility is located at 35 South West Boulevard, and is located primarily within the Borough of Newfield, Gloucester County, New Jersey. The manufacturing portion of the facility and associated support areas comprise approximately 67.5 acres. SMC also owns 19.8 acres of farmland (Farm Parcel), located approximately 2,000 feet southwest of the main facility in Vineland. The Hudson Branch, an intermittent stream, runs along the southern edge of the manufacturing portion of the facility and discharges to Burnt Mill Pond.

The manufacturing portion of the Site has a lengthy industrial history, beginning with glass manufacturing in the early 1900s. SMC first occupied the Site in 1952, operating a specialty metal plant producing chromium alloys, ferro-alloys, and other metallic products. Potassium perchlorate was used as an oxidizer in the on-Site furnace to increase temperature and enhance furnace performance. SMC's active manufacturing operations at the Site ceased in 2007. The manufacturing portion of the Site is currently used for general warehousing/leasing and administrative purposes. Current and historical use of the Farm Parcel, southwest of the manufacturing facility, is agricultural.

Previous Site investigations show concentrations of perchlorate, chromium and volatile organic compounds (VOCs), primarily trichloroethene, in groundwater. The primary contaminants in soil are chromium and vanadium, which are currently being remediated under Operable Unit 2.

5.2 Task Descriptions

Task 1: Drilling – Soil Logging, Groundwater Sampling via PushAhead™ and Well Installation

Ten borings will be advanced to depths up to ~140 ft bgs using a MiniSonic drill rig. Soil cores will be logged. Groundwater samples will be collected every 20 ft using the PushAhead™ sampling method. Upon receipt of groundwater sample analyses, installation of well nests (three wells, one each in the shallow, intermediate and deep zones) may occur.

Task 2: Groundwater Sampling

A groundwater sampling event will be performed, with groundwater being collected from shallow, intermediate, and deep wells for perchlorate and biogeochemical parameters. Groundwater samples will be collected from each of the selected monitoring wells utilizing low-flow purging and sampling methods. Further details are provided in the Task Hazard Analysis (THA) in Appendix B.

5.3 Chemical Hazards

The classes of chemicals that are known or suspected to be present that may be encountered while performing the work include the following:

- Perchlorate
- VOCs

Controls for these hazards are presented in the THAs included in Appendix B. A summary of these chemical hazards is presented in Appendix C.

5.4 Physical Hazards

The following physical hazards have been identified associated with the work to be performed and the Site conditions.

- Compressed gases
- Drum and container handling
- Electrocution
- Eye injury
- Hand/foot injury
- Heat stress
- Heavy equipment
- Knives/blades
- Lifting heavy loads
- Slips, trips, and falls
- Utility protection

Controls for these hazards are presented in the THAs included in Appendix B.

5.5 Biological Hazards

The following biological hazards have been identified associated with the work to be performed and the Site conditions.

- Allergic reaction to poisonous plants
- Biting/stinging insects
- Lyme disease and other diseases transmitted by pests
- Rats/vermin
- Snakes

Controls for these hazards are presented in the THAs included in Appendix B.

6. GENERAL SAFE WORK PRACTICES

The following general safe work practices must be adhered to while performing Site work:

- Basic personal protective equipment (PPE) shall be worn, including hard hats, safety glasses, hard-toed boots, and high-visibility vests. If conditions allow, the requirement for hard hats may be reduced with approval of the SHSO and PM. Flame resistant (FR) clothing is required while working on Site.
- Minimize contact with impacted materials. Do not place equipment on the ground. Do not sit or kneel on potentially contaminated surfaces.
- Smoking, eating, or drinking after entering the work zone and before personal decontamination is not allowed. Employees who are suspected of being under the influence of illegal drugs or alcohol will be removed from the Site. Workers taking prescribed medication that may cause drowsiness shall not operate heavy equipment and are prohibited from performing tasks where Level C or B PPE is required.
- Practice good housekeeping.
- Use of contact lenses is not allowed under certain hazardous working conditions.
- The following conditions must be observed when operating a motor vehicle:
    - Wearing seat belts is mandatory.
    - The use of headlights is mandatory during periods of rain, fog, or other adverse weather or low-light conditions.
    - A backup warning system or use of vehicle horn is mandatory when the vehicle is engaged in a backward motion.
    - Posted traffic signs and directions from flagmen must be observed.
    - Equipment and/or samples transported in vehicles must be secured from movement.
    - The use of vehicles acquired by Geosyntec by non-Geosyntec personnel is prohibited.
- In an unknown situation, always assume the worst reasonable conditions.
- Be observant of your immediate surroundings and the surroundings of others. It is a team effort to notice and warn of dangerous situations. Withdrawal from a hazardous situation to reassess procedures is the preferred course of action.
- Conflicting situations may arise concerning safety requirements and working conditions. These must be addressed and resolved rapidly by the SHSO and PM to relieve motivations or pressures to circumvent established safety policies.
- Unauthorized breaches of specified safety protocol are not allowed. Workers unwilling or unable to comply with established procedures will be asked to leave the Site.

7. EMERGENCY RESPONSE

This section discusses emergency response procedures and response equipment to be maintained on-Site. A table presenting a list of contacts and telephone numbers for the applicable local and off-Site emergency responders is provided in Section 3 of this HASP.

7.1 Injury and Emergency Response Procedures

In the event of an **injury** to an employee, the instructions for injury response and reporting, located in the **H&S Incident Response Procedures** instruction chart in the front of this HASP, must be implemented immediately. In the event that an **emergency** develops, the following procedures are to be implemented:

- The SHSO, or designated alternate, should be immediately notified via the on-Site communication system. The SHSO assumes control of the emergency response.
- If applicable, the SHSO must immediately notify off-Site emergency responders (e.g., fire department, hospital, police department, etc.) and must inform the response team of the nature and location of the emergency on-Site.
- If applicable, the SHSO may call for evacuation of the Site. Site workers should move to the rally point located in the western employee parking lot near the Site entrance/exit point provided on the Site Map.
- For small fires, flames should be extinguished using the appropriate type of fire extinguisher. Large fires should be handled by the local fire department.
- If a worker is injured, the procedures presented in “Instructions for Injury Response,” located in the front of this HASP, must be implemented immediately.
- After an incident has stabilized, the procedures presented in “Instructions for Incident Reporting,” located in the front of this HASP, must be followed.

7.2 Emergency Response Equipment

Emergency response equipment will be maintained in the work area as necessary for this project. Examples of emergency response equipment include first aid kits, fire extinguishers (Type ABC), and eyewash bottles.

8. KEY PERSONNEL AND HEALTH AND SAFETY RESPONSIBILITIES

Project personnel and their responsibilities in regard to health and safety concerns on this project are as follows:

Project Manager (PM): Seth Kellogg

- Approve this HASP and amendments, if any;
- Monitor the field logbooks for health and safety work practices employed;
- Coordinate with SHSO so that emergency response procedures are implemented;
- Check that corrective actions are implemented;
- Check and document that qualified personnel receive this plan and are aware of its provisions and potential hazards associated with Site operations, and that they are instructed in safe work practices and familiar with emergency response procedures; and
- Provide for appropriate monitoring, PPE, and decontamination materials.

Site Health and Safety Officer (SHSO): Jessica Evans

- Prepare and implement project HASP and amendments, if any, and report to the PM for action if deviations from the anticipated conditions exist and authorize the cessation of work if necessary;
- Check that Site personnel meet the training and medical requirements;
- Conduct pre-entry briefing and daily tailgate safety meetings;
- Check that monitoring equipment and PPE are operating correctly according to manufacturer's instructions and such equipment is used by on-Site personnel. Calibrate or check calibration of monitoring equipment and record results;
- Check that decontamination procedures are being implemented;
- Implement Site emergency response and follow-up procedures;
- Notify the HSC in the event an emergency occurs; and
- Perform and document weekly inspections.

Health and Safety Coordinator: Matt Mraw

- Review and audit HASP and amendments;
- Notify Director of H&S when an emergency occurs;
- Assist with the implementation of the corporate health and safety program; and
- Consult with staff on health and safety issues.

Site Workers:

- Provide verification of required health and safety training and medical surveillance prior to arriving at the Site;
- Notify supervisors of workplace accommodation requirements as the result of physical limitations or medical conditions;
- Attend pre-entry briefings and daily tailgate safety meetings;
- Immediately report accidents and/or unsafe conditions to the SHSO;
- Be familiar with and abide by the HASP; and
- Be ultimately responsible for his or her own safety.

9. WORKER TRAINING AND MEDICAL SURVEILLANCE

Personnel involved in field activities subject to OSHA HAZWOPER 29 Code of Federal Regulations (CFR) 1910.120 will be required to participate in both a health and safety training program that complies with criteria primarily set forth by the OSHA HAZWOPER in 29 CFR 1910.120(e) and a medical surveillance program covered under 29 CFR 1910.120(f), or equivalent regulations based on the jurisdiction in which the project is performed.

9.1 Pre-Assignment and Annual Refresher Training

Prior to arrival on-Site, the Geosyntec PM will be responsible for monitoring that their staff meet the requirements of pre-assignment training (40/24 hours per Procedure HS 301). In addition, personnel must be able to document dates of attendance at an annual 8-hour refresher and three days of fieldwork under a qualified supervisor. Failure to provide this documentation will prohibit entry to the active work area(s) (i.e., Exclusion Zone).

9.2 Site Supervisor Training

Consistent with OSHA 29 CFR 1910.120 (e)(4), prior to arrival on-Site, individuals designated as Site supervisors require an additional eight hours of specialized training.

9.3 Initial Site Safety Orientation and HASP Review

In addition to complying with 29 CFR 1910(e), Site personnel will attend an initial safety orientation during which the HASP and applicable THAs will be reviewed prior to initiating field activities. Site personnel will also attend an orientation conducted by the Site facility manager. This review will include the following:

- Understanding the lines of authority regarding health and safety and Site personnel roles and responsibilities;
- Information of specific hazard agents related to the Site and Site operations will be discussed, such as health hazards of Site chemicals and specific safety hazards of processes, tools, and equipment;
- Training in the proper use, maintenance, and decon protocol of PPE and Level(s) of Protection;
- Appropriate work practices and engineering controls to reduce/eliminate exposures to Site hazards will be reviewed;
- Personnel will be informed of means for normal Site and emergency communication(s);
- Air monitoring strategies will be discussed to include the frequency/types, action levels, sampling techniques, pre/post calibration techniques;
- Unique/Site specific medical surveillance requirements that need to be considered based on Site contaminants;
- Understanding Site control measures, work zones, and proper decontamination procedures for personnel/tools/vehicles, etc. to reduce the potential for both on-/off-Site contamination;

- Personnel will be trained to respond quickly and properly in the event of an emergency; and
- Personnel involved in specific hazardous activities, such as confined space entry, drum handling, sampling unknowns, etc. will receive specialized training in the appropriate techniques to employ prior to commencing these operations.

9.4 Baseline Medical Surveillance Exam

The baseline medical examination is used to identify physical capabilities and certain medical limitations that may have an impact on the candidate's ability to perform in the position and/or job activity for which he/she is being considered, as well as to establish certain baseline medical parameters. The initial test results can then be compared against future periodic or project-specific monitoring results.

9.5 Periodic/Annual/Biennial Medical Exam

The periodic medical examination is used to evaluate an employee's continued fitness for duty and to assess possible impact(s) occupational exposures may have had on their health status. The periodic examination includes an update to the medical and work history, results of previous occupational exposure assessments, and a detailed medical exam tailored to the job description.

The Medical Director from WorkCare determines the frequency of the periodic medical exams based on regulatory requirements, the position/work activities of the employee, and the level of exposure to physical, chemical, and biological agents.

9.6 Exposure/Activity/Project-Specific Medical Testing

Exposure-specific medical tests and/or evaluation of biological indices may be conducted to establish a baseline for certain project-specific parameters, to monitor the effectiveness of hazard controls, and/or to assess the impact of occupational exposures associated with a particular work activity or project. The Medical Director, in coordination with the H&S Department, will require or recommend an exposure-specific exam when deemed appropriate based on knowledge of project hazards, occurrence of employee health symptoms, or an unexpected exposure event. Requests for exposure-specific examinations will be forwarded to the H&S Department, who will process the requests in collaboration with the Medical Director. The Medical Director will determine the type and frequency of the exposure-specific medical exams for employees designated to participate based on sound medical practice, latest toxicology information, and current regulatory requirements.

9.7 Exit Exam

An exit medical examination is offered when an employee leaves the medical surveillance program, either because of termination of employment with Geosyntec or because of reassignment to a position not designated or identified to participate in the medical surveillance program. This optional exit examination may be used to assess potential changes in medical status that have occurred during the course of employees' previous work activities, and to establish a medical baseline at the time of departure.

10. MAPS AND SITE CONTROL

10.1 Routes to Hospital and Urgent Care Facility

A hospital and an urgent care facility near the Site have been identified. Maps to the hospital and urgent care are included after the Table of Contents of this HASP. Both figures also include the facility name and phone number.

10.2 Site Maps

The on-Site map and off-Site map are located in the front of this HASP. The maps are intended to provide on-Site, Farm Parcel, and off-Site area orientation and to delineate the rally point. The work zone(s) exist at each well location where groundwater will be sampled. Changes may be made to the Site maps by the SHSO based on changing Site conditions. The Site maps should be accessible in the work area.

10.3 Buddy System

The buddy system is required when work is performed in hazardous areas. The buddy system includes maintaining regular contact with one or more on-Site Geosyntec personnel, clients, and/or contractors to periodically check on the condition of Site workers such that each employee in the work group is observed by (or in verbal contact with) at least one other employee in the work group. For field visits with only one employee on-Site, the buddy system shall be implemented via periodic telephone contact with off-Site Geosyntec personnel. The purpose of the buddy system is to provide rapid assistance to employees in the event of an emergency.

10.4 Controlled Work Zones

APPLIES TO TASK: ☒① ☒② ☐③ ☐④ ☐⑤ ☐⑥ ☐⑦ ☐⑧ ☐ NOT APPLICABLE

Three controlled work zones, including an Exclusion Zone, a Contaminant Reduction Zone (CRZ), and a Support Zone, are required for the task(s) indicated above. Geosyntec employees must not be allowed into the CRZ or Exclusion Zone or the Work Zone until they have received the proper personal protective equipment (PPE) and they have read, understand, and meet the requirements outlined in this HASP. The Exclusion Zone is defined as the area on-Site where contamination is suspected and tasks are to be performed. The CRZ is defined as the area where equipment and workers are to be decontaminated as they leave the Exclusion Zone. The Support Zone is defined as the command area and may serve as a staging and storage area for supplies. The location and extent of the work zones may be modified as necessary as Site investigation information becomes available. For Sites that do not require the three controlled work zones, the area(s) where work is to be performed shall be called the Work Zone.

Visitors to the Site may need to be continually escorted for safety purposes. Visitors under Geosyntec's direction need to check in with the SHSO upon visiting the Site.

For the tasks identified above, the boundaries of the Exclusion Zone, CRZ, and Support Zone, or the Work Zone, shall be marked using appropriate methods, including but not limited to warning tape, signs, traffic cones, fencing, or other appropriate means.

10.5 Site Access

Certain Sites require controlled access to the work area. Examples of access controls include sign in/sign out logs, checking in with guards, and donning identification badges. Geosyntec personnel will adhere to the Site-specific access requirements and monitor that subcontractors and other Geosyntec visitors abide by Site-specific access control requirements.

10.6 Inspections

☐ APPLICABLE ☒ NOT APPLICABLE

Based on the hazards identified for the project, periodic health and safety inspections may be performed. The H&S Inspection Checklist records should be kept on file at the project Site. The frequency for periodic inspections is:

☐ Weekly

☐ Monthly

☐ Other: _____

11. TAILGATE MEETINGS

Tailgate meetings must be held daily prior to starting work to discuss important health and safety issues concerning tasks to be performed during that shift. Non-Geosyntec Site workers should also communicate health and safety concerns associated with the tasks they will be performing. Topics discussed in the tailgate meetings must be documented.

12. STOP WORK AUTHORITY

In accordance with the Company's Procedure HS 203 – Stop Work Authority, Geosyntec personnel and subcontractor personnel have the authority and responsibility to issue a Stop Work Order if unsafe actions and/or conditions are identified. The Stop Work Authority (SWA) process involves a stop, notify, correct, and resume approach for resolving observed unsafe work actions or conditions. The person issuing the work stoppage will first notify workers engaged in or affected by the unsafe activity or condition and require that associated work be stopped. After this Stop Work Order is issued, the Geosyntec project manager and the supervisors for affected or concerned contractors will also be notified. The Geosyntec project manager will document the issuance of the Stop Work Order on the form provided in Procedure HS 203. Work will not resume until the issues and concerns of the Stop Work Order have been adequately addressed.

13. AIR MONITORING

APPLIES TO TASK: ☒① ☒② ☐③ ☐④ ☐⑤ ☐⑥ ☐⑦ ☐⑧ ☐ NOT APPLICABLE

Air monitoring will be performed to evaluate airborne chemical and/or dust exposure levels within the breathing zone of Site workers. Hazardous conditions may include concentrations that may cause acute or chronic illness, potential oxygen deficient environments, or potential explosive environments. Air monitoring may also be performed to evaluate the adequacy of engineering, administrative, and/or PPE controls. Air monitoring may be "real-time" (e.g., the instrument provides immediate results at the project), using multi-gas meters, photoionization detectors (PIDs), or colorimetric tubes. Personal monitoring may also be performed by collecting samples and forwarding to a laboratory for analysis and quantification.

The type(s) of air monitoring equipment required and associated action levels are outlined in Appendix D. Monitoring equipment must be calibrated based on the manufacturer's requirements. Calibration results and air monitoring measurements must be documented. Based on the results noted and Site activities or scope of work changes, the frequency of air monitoring may be adjusted on Site by the SHSO with the consent of the Project Manager and communication with the HSC.

14. PERSONAL PROTECTIVE EQUIPMENT

The levels of PPE required for each task are presented in

Appendix E. Required equipment and types of protective clothing materials, as well as an

	Task ①	Task ②	Task ③	Task ④	Task ⑤	Task ⑥	Task ⑦	Task ⑧
Potential PPE Lev per Task:	D C	D C	D C	D C	D C	D C	D C	D C

indication of the initial level of protection to be utilized, are listed. The level of protection may be upgraded or downgraded by the SHSO according to controls requirements in

Appendix E or according to action levels provided in Appendix D.

If

	Task ①	Task ②	Task ③	Task ④	Task ⑤	Task ⑥	Task ⑦	Task ⑧
Potential PPE Lev per Task:	D C	D C	D C	D C	D C	D C	D C	D C

respirators are worn, workers must abide by the company's Respiratory Protection Program in accordance with company's Respiratory Protection Program (HS 112).

15. DECONTAMINATION

The SHSO and Project Manager will determine the type and level of decontamination procedures for both personnel and equipment based on evaluation of specific work activities in the controlled work zones. Medical treatment will take precedence over decontamination in the event of a life threatening and/or serious injury/illness. Personnel will perform decontamination in designated and identified areas upon leaving “hot zones” where the potential exists for exposure to hazardous chemical, biological, or environmental conditions.

Decontamination of personnel in Level D (modified) will consist of proper containerization and disposal of coveralls, disposable boots, and gloves (if applicable).

Decontamination of personnel in Level C, if applicable, will consist, at a minimum, of:

- Removal and cleaning/disposal of boot covers, coveralls, and outer gloves;
- Removal, cleaning, and storage of respiratory protection;
- Washing of non-disposable PPE suspected of being contaminated using a soap solution followed by a water rinse; and
- Removal and disposal of inner gloves.

Hand tools and sampling equipment shall be decontaminated as needed by washing in decontamination basins with appropriate solutions, or, if possible, by dry decontamination. Wash solutions and PPE may require disposal at a licensed waste facility.

16. SPILL CONTAINMENT

The task(s) for this project may involve the handling of drums and/or containers that contain stored chemicals, hazardous materials, and/or wastes. The drums and/or containers may have been spilled/dislodged during Site activities due to compromised construction of the drum/container, transportation accidents, improper packaging practices, and improper handling of hazardous materials during on/off loading. Containers shall be inspected and their integrity assured prior to being moved and/or handled. If the integrity of the container is in question, the container shall be over packed or its contents transferred. Operations shall be organized and coordinated to minimize movement of such containers. Where spills, leaks, or ruptures may potentially occur, a supply of sorbents shall be located in the immediate area. Additional preventative measures include:

- UN-approved 55-gallon drums, bins, and/or Baker tanks will be inspected for visible defects upon delivery to the Site;
- UN-approved 55-gallon drums will also be inspected to ensure each drum includes a resealable lid with a small resealable sampling port near the top, or on the side of the drum and that the enclosure is not deformed and/or distorted;
- Drums will not be completely filled to allow for possible expansion of liquid and will be set on wooden pallets to facilitate transport by forklift;
- The storage area will be inspected to check for leaks weekly while the containers are being filled and immediately after a relocation to a temporary on-Site storage area; and
- Flat areas away from high-traffic work areas/zones and storm/sewer drains will be selected for temporary storage.

In the event of an unplanned release or spill of unknown or hazardous substances, the Site supervisor will designate personnel who will support the spill containment, control, and/or clean-up procedures. The team will request additional off-Site emergency response assistance if necessary based on the type of spill, volume, potential toxicity, etc.

The spill area will be isolated and restricted to only authorized personnel designated to assist with the containment, control, or clean-up activity. Authorized personnel will be trained to contain and clean spills from typical materials and quantities used at the project location. Physical barriers will be set up to warn unauthorized personnel to stay clear and evacuate the affected area. The spill, leak, or incident will be assessed by the team and characterized to determine the appropriate course(s) of action(s) to consider:

- Small spills (i.e., maximum volume of 55 gallons of a liquid or 100 pounds of a solid) may be remediated using absorbent materials by designated personnel;
- Large spills (i.e., liquid volumes greater than 55 gallons or solid weights greater than 100 pounds) and/or spills of highly toxic materials may require assistance by off-Site hazardous materials (HAZMAT) teams;

- Attempts shall be made to identify and stop the source(s) of spillage immediately while donning proper PPE (based on action levels and the air monitoring program) and performing air monitoring;
- The Site supervisor will direct spill-response operations and stay at the spill area until it has been cleaned, inspected, and cleared for re-entry; and
- The Site supervisor will prepare a spill incident and clean-up report and will communicate findings to the Project and Branch Manager and H&S Department.

17. CONFINED SPACE ENTRY

☐ APPLICABLE ☒ NOT APPLICABLE

The task(s) for this project involve confined-space entry. Workers must abide by the company's Confined Space Entry Program (Procedure HS 118).

18. GLOBALLY-HARMONIZED SYSTEM FOR HAZARD COMMUNICATION

☒ APPLICABLE ☐ NOT APPLICABLE

The following procedures must be followed for chemicals brought onto the Site by Geosyntec personnel or by subcontractors (i.e., decontamination solution, sampling preservatives, KB-1® solution, sodium permanganate, etc.) while performing the tasks of this project:

- Labels on primary chemical containers must not be defaced;
- Chemicals must be stored in appropriate storage containers;
- Secondary containers and storage cabinets must be correctly and clearly labeled;
- Chemicals incompatible with each other must not be stored together;
- Workers must receive training on the chemical hazards; and
- Safety Data Sheets (SDSs) must be added to Appendix F.

When chemicals are used on-Site, workers must abide by Geosyntec's GHS Hazard Communication Program (Procedure HS 115).

19. HASP AMENDMENTS

Over the course of this project, it is possible that the project-specific hazards and working conditions will change. This HASP may be reviewed and amended as necessary to effectively describe the changing working conditions and measures to mitigate the potential health and safety issues that may arise during the project. Amendments to the HASP should be briefly described in the following spaces provided. The full text of the amendments should be provided in Appendix A and/or additional THAs should be added to Appendix B.

AMENDMENT 1:

Date: 6/1/2020 Project Manager: Seth Kellogg HSC: Jessica Evans

Brief Description of Amendment:
A guidance document titled Field Work COVID-19 General Prevention Measures has been added to this Health and Safety Plan as Appendix G to provide field staff with the best practices to reduce the risk of spreading the COVID-19 virus.

AMENDMENT 2:

Date: 8/4/2020 Project Manager: Seth Kellogg HSC: Caroline Kellner

Brief Description of Amendment:
A THA titled "Drilling – Soil Logging, Groundwater Sampling via PushAhead™ and Well Installation" has been added as Task 1 due to a change in the scope of work.
The THA for "Groundwater Sampling" has been shifted from Task 1 to Task 2 to reflect the new order of events.

AMENDMENT 3:

Date: _____ Project Manager: _____ HSC: _____

Brief Description of Amendment:

Appendix A: HASP Amendments

Discuss details of amendments to this HASP here. Include amendment number, date, and details of amendments.

Appendix B: Task Hazard Analyses

TASKS	
① Drilling – Soil Logging, Groundwater Sampling via PushAhead™ and Well Installation	⑤
② Groundwater Sampling	⑥
③	⑦
④	⑧

THAs for these tasks are presented in the following pages.

Geosyntec consultants

TASK HAZARD ANALYSIS (Ver. 2, June 2015)

Geosyntec HS Procedures referenced herein are available on Geosyntec's H&S SharePoint site and should be consulted, as appropriate, per project-specific needs. This THA prepared per HS-106-Accident Prevention Program, HS-204-Task Hazard Analysis, and meets the requirements for a "Site-Specific Health and Safety Plan" per Geosyntec HS Procedures and regulations referenced herein (see Section B.14.).

PART A – SITE SAFETY PLAN

A.1. PROJECT/TASK INFORMATION

TASK:	Drilling – Soil Logging, Groundwater Sampling via PushAhead™ and Well Installation		
Project Name:	Shieldalloy Metallurgical Corporation OU3	**Project Number/Org:**	JR0241
Project Address:	35 West Boulevard Newfield, NJ		
Description of Task & Worksite:	Ten borings will be advanced to depths up to ~140 ft bgs using a MiniSonic drill rig. Soil cores will be logged and containerized in an open top drum. Groundwater samples will be collected every 20 ft using the PushAhead™ sampling tool on a MiniSonic drill rig and a bailer. Groundwater is anticipated to be impacted with perchlorate and volatile organic compounds. All purge water will be containerized in closed top drums.Upon receipt of groundwater sample analyses, installation of well nests (three wells, one each in the shallow, intermediate and deep zones) may occur. The Site was formerly a manufacturing facility but operations have ceased and the Site is now used for general warehousing/leasing, and administrative purposes.		

Geosyntec Personnel	**Name**	**Desktop Office Phone**	**Cell Phone**
Site Lead/HS Officer	Caroline Kellner	(609) 493-9016	(609)721-2467
Project Manager	Seth Kellogg	(609) 493-9018	(732) 354-8463
Project Director	John Persico	(609) 493-9008	(609) 903-6227
HS Coordinator	Matt Mraw	(609) 493-9004	(609) 462-1198
Regional HS Mngr.	Mark Malchik	(978) 206-5777	(781) 392-5440
Corp. HS Director	Bob Poll	(813)379-4420	(813)240-9231
Client Contact(s):	John Hunt	(484)582-3519	(617)957-5961
Subcontractor(s):	☐ Not Applicable ☒ Applicable, provide contact information below:		
	William Armstrong (Cascade Drilling, L.P.)	(609) 685-2223	**TBD**

A.2. EMERGENCY RESPONSE

Based on analysis of worksite factors, client/regulatory requirements, availability of emergency services.

Consider all Relevant Risk Factors & Response Procedures *(fire/explosion, medical, chemicals/spills, security, site factors, weather, communications)*.
EXPLANATORY NOTES, CLARIFICATIONS:
In case of life-threatening emergency, immediately dial 911. Once the situation is stabilized, contact the Geosyntec project manager.

Available Means of Jobsite Emergency Communication/Alerting	☒ Verbal ☒ Cell Phone ☐ Land Line ☐ 2-Way Radio ☐ On-site alarm/signal system ☐ Other:
To Summon Emergency Services Police, Fire, Ambulance	☒ **DIAL 911**, for external responders ☐ **Other**:
Other Emergency Contacts, as needed *(such as security, spill responder, utility):*	Gas Utility: PSE&G – 1800-436-7734 or 1800-880-7734 Electrical Utility: PSE&G: 1800-436-7734 or 1800-880-7734 Unknown Utility: 811
Nearest Emergency Medical Services	Hospital Name: Inspira Medical Center Vineland Address: 1505 W Sherman Ave Vineland, NJ 08360 Phone #: (856) 641-8000 Phone #: (856) 641-8000
For **Non-Emergency Urgent Care**	☒ Contact WorkCare, 24/7 at: 888-449-7787 ☒ Other: Inspira Urgent Care (856) 507-8548 1297 W Landis Ave, Vineland, NJ 08360
Job-site **Evacuation** Procedure, Rally Point, Place of refuge:	In case of evacuation, on-Site workers must meet at Site entrance on West Boulevard. Exit must be kept open for emergency vehicles.
Special Emergency Equipment/Procedures	No special procedures.

IMPORTANT: After initial emergency response actions and incident stabilization, contact appropriate project personnel listed in Part A.1.

A.3. SUMMARY OF WORK STEPS, HAZARDS, CONTROLS Based on **PART B, "HAZARD ANALYSIS,"** and worksite/client/project factors.		
WORK STEPS	**HAZARDS**	**CONTROLS**
1) ***Travel to site**: Geosyntec and Cascade (the drilling subcontractor) travel to Site*	- *Routine driving hazards* - *COVID-19 transmission*	- *Defensive driving practices* - *Limit stops and wash hands immediately following stops* - *For more detail, see B.1, B.2, COVID-19 Addendum*
2) ***Verify locations of soil borings :** Geosyntec and Cascade will review One-Call utility markouts and the physical vicinity of drilling to confirm drilling locations.*	- *Underground utility hazards* - *Weather-related hazards such as sun exposure and/or potential for extreme temperatures*	- *Complete utility checklist prior to drilling* - *Hand clear locations to 5 ft* - *For more detail, see B.1, B.9, Utility Checklist*
3) ***Mobilization of rig/equipment and pre-sampling set-up**: Cascade will maneuver rig to the boring location, stage support vehicles and mark out work zone. Geosyntec will conduct a tailgate safety meeting with field personnel and establish work areas*	- *Street traffic* - *Heavy lifting* - *Weather-related hazards such as sun exposure and/or potential for extreme temperatures* - *COVID-19 transmission*	- *Proper PPE – including high visibility vest, steel toe boots, safety glasses, and nitrile gloves.* - *Use proper lifting techniques* - *Use cones and back up spotter as necessary* - *Follow COVID-19 Best Practices including social distancing and wearing masks as necessary* - *For more detail, see B.1, B.2 , COVID-19 Addendum*
4) ***Hand Clearing:** Cascade will soft dig to 5 ft bgs using air knife and vaccum.*	- *Compressed Air* - *Heavy lifting* - *Exposure to Site contaminants* - *Weather-related hazards such as sun exposure and/or potential for extreme temperatures*	- *Proper PPE – including high visibility vest, steel toe boots, safety glasses, and nitrile gloves.* - *Compressed air safety including whip checks* - *For more detail, see B.1, B.2, B.5, B.13, B.9*

5) ***Borehole Advancement:*** *Cascade will drill to specified depth using a MIniSonic drill rig with a 4-inch diameter bit. Geosyntec will log cores & screen using a PID. Cascade and Geosyntec will collect groundwater samples using a PushAhead™ sampler and a bailer.*	- *Exposure to Site contaminants* - *Pinch points* - *Power tools* - *Noise caused by rig and power tools* - *Heavy lifting* - *Weather-related hazards such as sun exposure and/or potential for extreme temperatures* - *COVID-19 transmission*	- *Proper PPE – including high visibility vest, steel toe boots, safety glasses, and nitrile gloves.* - *Wear work gloves while operating around the drill rig. Be aware of moving and rotating parts.* - *Use work gloves and safety glasses while operating power tools. Always follow the intended use of each power tool.* - *Wear hearing protection as needed while drill rig and power tools are in operation.* - *Use proper lifting techniques. Lift with your legs not your back, and all equipment and supplies over 50 pounds require a two man lift.* - *Drillers should maintain social distance or utilize masks if unable to maintain distance.* - *For more detail, see B.1, B.2, B.5, B.6, B.8, B.11, B.14, C.1, COVID-19 Addendum,*
6) ***Borehole Grouting:*** *Cascade will remove drill rods and pressure-grout the borehole to the ground surface.*	- *Exposure to Site contaminants* - *Pinch points* - *Power tools* - *Noise caused by rig and power tools* - *Heavy lifting* - *Weather-related hazards such as sun exposure and/or potential for extreme temperatures* - *COVID-19 transmission*	- *Proper PPE – including high visibility vest, steel toe boots, safety glasses, and nitrile gloves.* - *Wear work gloves while operating around the drill rig. Be aware of moving and rotating parts.* - *Use work gloves and safety glasses while operating power tools. Always follow the intended use of each power tool.* - *Wear hearing protection as needed while drill rig and power tools are in operation.* - *Use proper lifting techniques. Lift with your legs not your back, and all equipment and supplies over 50 pounds require a two man lift.* - *Drillers should maintain social distance or utilize masks if unable to maintain distance.* - *For more detail, see B.1, B.2, B.5, B.6, B.8, B.11, B.14, C.1, COVID-19 Addendum,*

7) ***IDW Disposal:*** *Soils will be containerized in a sealed and labelled open-top drum and stored on-Site until pickup. Purgewater will be containerized in a sealed and labelled closed-top drum and stored on-Site until pickup.*	- *Dermal exposure to contaminants in soil* - *Heavy lifting*	- *Proper PPE – including high visibility vest, steel toe boots, safety glasses, and nitrile gloves.* - *Use proper lifting techniques* - *For more detail, see B.1, B.13, and B.14*
8) ***Equipment decontamination****: Equipment exposed to soil will be deconned with alconox solution and distilled water. Decon fluid is drummed with purge water.*	- *Dermal exposure to contaminants in soil* - *Heavy lifting*	- *Proper PPE – including high visibility vest, steel toe boots, safety glasses, and nitrile gloves.* - *Use proper lifting techniques* - *For more detail, see B.1, B.13, and B.14*
9) ***Demobilization****: Cascade will transport rig back to trailer. Drilling area will be cleaned and any residual soil will be swept. All equipment will be packed into the field vehicle. Geosyntec on-Site personnel will notify project manager that the work is completed.*	- *Exposure to Site contaminants* - *Heavy lifting*	- *Proper PPE – including high visibility vest, steel toe boots, safety glasses, and nitrile gloves.* - *For more detail, see B.1, B.8, and B.13*
10) ***Travel off-site****: Geosyntec and Cascade Drilling leave Site*	- *Routine driving hazards* - *COVID-19 transmission*	- *Defensive driving practices* - *COVID-19 best practices, including limiting stops during travel* - *For more detail, see B.1, COVID-19 Addendum*
11) ***Monitoring Well Installation****: Following receipt of groundwater sample analysis results, monitoring wells may be installed at selected locations. Aspects of work steps 1-10 will be repeated.*	- *See "Hazards" for work steps 1-10*	- *See "Controls" for work steps 1-10*

A.4. H&S EQUIPMENT LIST List worksite equipment for worker protection; provide details in Explanatory Notes, Clarifications.

EXPLANATORY NOTES, CLARIFICATIONS: High vis vest, hard-toed boots, and safety glasses must be worn at all times by onsite personnel. A hard hat must be worn when within 25 ft of the drill rig. Hearing protection must be worn when the drill rig is in operation. Nitrile gloves must be worn when handling soils and groundwater. Geosyntec and the drilling subcontractor will both have a first aid kit on hand. Drilling subcontractor will have a fire extinguisher readily available. Drilling subcontractor will point out the location of the fire extinguisher to Geosyntec personnel. Drilling subcontractor is responsible for marking out work zone with traffic control devices such as cones or similar. Non-standard PPE includes a facial barrier (i.e., mask) that should be used as defense against COVID-19 transmission if social distance cannot be maintained.

☒	**ROUTINE PPE**	☒ Standard work clothes appropriate for task ☒ Hard-toed boots/shoes ☒ Hardhat ☒ Safety glasses	☒ Work gloves appropriate for task ☒ Noise/hearing protection ☒ High-visibility/reflective vest ☐ Ice creepers (boot attachments)
		☒ Basic PPE for protection from low-hazard chemical contact & dust (nitrile gloves, Tyvek suit, dust mask, boot covers).	
☒	**ROUTINE H&S EQUIPMENT/GEAR**	☒ First Aid Kit ☒ Fire extinguisher ☒ Emergency eyewash bottle(s) ☐ Insect control (repellant, wasp spray, other) ☐ Caution tape	☐ Sun protection (sunscreen, shade canopy, other) ☒ Project-supplied drinking water and/or hygiene facilities ☐ Poison ivy skin wash (Technu or similar) ☒ Vehicle emergency kit (flares, lights, reflective device) ☒ Traffic control warning devices (cones, or similar)

		☐ Other:		
☒	**NON-ROUTINE PERSONAL PROTECTIVE EQUIPMENT (PPE)** (Indicate specific types of PPE in Explanatory Notes, Clarifications)	☐ Goggles and/or face shield ☐ Chemical protective gloves ☐ Coveralls (Tyvek, or other) ☐ Outer boots, boot covers	☐ Disposable n-95 dust mask ☐ Half-face respirator (APR), cartridges ☐ Full-face respirator (APR), cartridges ☐ Personal flotation device	☐ Fire retardant clothing ☐ Arc Flash Protection ☐ Electrical-Hazard-rated boots, gloves ☐ Personal fall apparatus
		☒ Other: Protective facial barrier for COVID-19		
☐	**SPECIAL HAZARD CONTROLS**	☐ Portable GFCI	☐ Lockout/tagout equipment	☐ Ventilation equipment (fan, blower)
		☐ Eyewash - 15 min. flow	☐ Emergency deluge shower	☐ Air horn, alarm
		☐ Other:		
☒	**DECON, PPE DISPOSAL**	☒ Receptacle for disposable PPE	☐ Hand washing provisions	☒ Decon solution, related supplies
		☐ Other:		
☒	**AIR MONITORING EQUIPMENT, OTHER EQUIPMENT FOR WORKER EXPOSURE TESTING**	List equipment/devices to be brought to worksite; Use in accordance with procedures in Part C: MiniRae PID or similar		

PART B – HAZARD ANALYSIS and CONTROLS *Complete Section B.1., then subsequent sections as applicable to the task(s).*

B.1. ROUTINE HAZARD PREPAREDNESS **This section required for all tasks.**

Explanatory Notes, Clarifications: The drilling locations are spread out across 67 acres and in public right-of-ways. Caution will be exercised driving to drilling locations, and personnel will maintain awareness of their surroundings. A flagger must be used when moving the drill rig. Insect repellant spray and/or long sleeves are recommended as biting insects and poisonous plants may be encountered. Insect repellant spray will be made available. High-vis vest, hard-toed boots, and safety glasses must be worn at all times. A hard hat must be worn when within 25 ft of the drill rig and hearing protection must be worn when the drill rig is in operation. Nitrile gloves must be worn when handling soil cores, groundwater, decon fluids, and equipment exposed to groundwater or soil. Good housekeeping must be maintained in the work zone to minimize trip hazards. Proper lifting techniques must be followed when moving equipment. Anything greater than 50 lbs requires a two-person lift. Cut-resistant protective gloves must be worn when cutting plastic sheeting. Protective gloves mustbe worn when lifting heavy equipment, opening or closing drum lids, and opening manhole covers. Sampling crews must adhere to the 30/30 rule for lightning and must seek shelter in a field vehicle. Crews must monitor for heat stress and drink plenty of fluids throughout the course of the day. Seek shade when needed and set up a canopy over the monitoring well if warranted due to high temperatures. Caution will be taken during driving and on-Site to avoid COVID-19 transmission.

General Safety, Wellness, Preparedness – **Delineate site-specific HS aspects, as appropriate, in "Explanatory Notes, Clarifications," above.**

☒ **General premises** hazards - housekeeping, rough terrain, trip hazards, steep slope, remote location.
☒ **Weather/climate-related hazards** – heat stress/cold stress measures, sun screen, severe weather shelter/refuge, "30/30 rule" for lightning
☐ **Plant/Insect/Animal Hazards** - Precautions: poison ivy wash; insect repellant; check for ticks; hornet nest spray; animal precautions.
☐ **Worksite traffic hazards** – Implement measures to protect personnel (high visibility/reflective clothing, on-person lighting, traffic control measures).
☐ **Illumination hazards/night work** - Illuminate work areas and/or access routes, use reflective/hi-visibility clothing or on-person lighting, as appropriate.
☒ **Lifting, manual material handling** – use proper lifting procedures, seek help for >50 lbs.

Geosyntec Procedures: *HS-124-Heat Stress, HS-125-Cold Stress, HS-127-Ticks, HS-208-Housekeeping, HS-210-Walking and Working Surfaces, HS-401-Back Injury Prevention, HS 517 Traffic Safety*

Routine Personal Protection – **Delineate site-specific HS aspects, as appropriate, in "Explanatory Notes, Clarifications," above.**

☒ **Head protection from overhead hazards** - Wear hardhat or "bump cap" as appropriate for hazard.
☒ **Hand protection** - Wear protective work gloves appropriate for the hazard and work tasks.
☒ **Eye protection** - Wear safety glasses (with side shield or wrap around, either clear or shaded for sun protection), or other appropriate eye protection.
☒ **Foot protection, rough terrain** - Wear work boots/shoes with hard toes, ankle support, puncture resistance, traction, as appropriate for conditions.
☒ **Hearing protection** – use earplugs, earmuffs (or both) as appropriate for conditions; at a minimum where noise levels exceed 85dBA.
☐ **Dust, unsanitary conditions** – For general protection against minimal non-specific hazards, use protective clothing and/or disposable dust mask, as needed.

Geosyntec Procedures: *HS-109-Hearing Conservation, HS 112-Respiratory Protection, HS-113-Personal Protective Equipment, HS-207-Working Alone, HS-105-Driver and Vehicle Safety*

Tools, Equipment, Machinery – **Delineate site-specific HS aspects, as appropriate, in "Explanatory Notes, Clarifications," above.**

☒ **Manual hand tools -** proper tool for the job, maintain in good condition, use vise/clamp to hold work piece, proper follow through, stay clear of "line of fire."
☒ **Knives, cutting tools -** Utility/folding/collapsible knives and fixed open-bladed knives/cutting tools are *not* permitted, unless specifically authorized. Cutting tools with automatically-retracting blades, or with enclosed/guarded blades are permitted. See HS-502-*Manual Hand Tools* for additional Information.
☒ ***Working near*** **powered tools/equipment/machinery** – safe distance, heed warning signs, stay out of "line of fire," use PPE (for eye/hearing/dust protection).
☒ ***Operation/use of*** **powered tools/equipment/machinery – See Section B.5.**

HS-502-Manual Hand Tools

Security– **Delineate site-specific HS aspects, as appropriate, in "Explanatory Notes, Clarifications," above.**

☐ **High crime, urban** – Use appropriate measures for personal security (such as buddy system, security service, work scheduling, other measures)
☐ **Working alone** - Establish "check in" procedure with supervisor/project manager.

Geosyntec Procedures: *HS-207-Working Alone*

Routine Driving Hazards – **Delineate site-specific HS aspects, as appropriate, in "Explanatory Notes, Clarifications," above.**

☒ **Routine work travel** - Use routine safe/defensive driving practices (seat belts, safe speeds, eyes ahead, no tailgating, limit distractions, safe cell phone use, no texting, clear windows, account for weather/road conditions, adequate sleep, other measures as appropriate).

☐ **Unfamiliar location** - Plan travel route before driving (assemble maps, enter destination in GPS).

☐ **Long Distance or During Sleep Hours** – Minimize fatigue: rest breaks, light snacks (avoid heavy meals), stay hydrated, fresh air, no loud music, clean windshield.

☐ **Unfamiliar vehicle** – Become familiar with vehicle operational controls and handling characteristics before operating vehicle.

Geosyntec Procedures: *HS-105-Driver and Vehicle Safety*

B.2. SPECIAL DRIVING/TRAFFIC/TRANSPORTATION HAZARDS ☒Applicable ☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS: Drilling subcontractor is responsible for safely driving rig/trailer and maneuvering the rig to the drilling location. Drilling subcontractor will use a flagger/spotter to safely maneuver the rig. Drilling subcontractor will stay alert of overhead hazards.

☐	**SPECIAL DRIVING HAZARDS** Off-Road Driving or use of non-typical vehicle, heavy vehicle, van, golf/utility cart, ATV Hazards: Worker injury due to vehicle collision, rollover	☐ For off road driving, do not exceed capability of vehicle, beware of wet conditions, speed low, avoid unsafe orientation on slopes. ☐ Follow ATV specific procedures for training, safety equipment, operation, manufacturer's instructions. ☐ Special Skills Required for Vehicle type - For vehicles requiring special skills (such as windowless van, heavy work vehicle, utility vehicle, similar) ensure operator is provided training and/or has appropriate operator skills through experience. ***Geosyntec Procedure(s):*** *HS-510-All Terrain Vehicles*
☒	**TRANSPORTING MATERIALS, TOWING/HAULING LOADS** Hazards: Vehicle accident, occupant injury from shifting load, unsafe equipment.	☒ Ensure load is firmly secured (rope, straps, load configuration) to prevent shifting during travel. ☒ Slings, chains, strap, rope and related equipment used for towing, hauling, load-securing shall be appropriate for use, and used in a manner as to prevent an unsafe condition. ☒ For trailer use, verify signal/braking lights operational, rear-view mirrors effective, hitch/safety chains secure.
☒	**WORKSITE TRAFFIC HAZARDS** Where the project worksite is located in/near vehicle thoroughfare. Hazards: Worker injury from being struck by vehicle traveling in thoroughfare.	☒ Wear reflective vests where exposed to traffic hazards. ☐ Where possible, park vehicles as protective shield from oncoming traffic. ☒ Configure work area and support vehicles to minimize worker exposure to traffic hazards. ☐ Use DOT signal devices to re-route vehicles around work area, site entrances/exits. ☐ Use DOT-trained flaggers or police detail where appropriate or required. ***Geosyntec Procedure(s):*** *HS-517-Traffic Safety*
☐	**RAILROAD HAZARD** Hazard: Worker injury from being struck by train in R.R. right-of-way	☐ Coordinate with rail company and implement required safety and security measures. ☐ Site workers to receive safety training for railroad work. **Geosyntec Procedure(s):** HS-305-Rail Operations
☐	**WATER TRANSPORTATION**	☐ Follow HS 312 "Water Transportation Safety," and Section B.3., "Water/Boating Hazards." **Geosyntec Procedure(s):** HS-312-Water Transportation Safety
☐	**AIRPORT, AIRCRAFT** Worker injury when working on/near airport runway, or use of helicopter, light aircraft	☐ Coordinate safety requirements with Airport personnel and implement required safety measures. ☐ Site workers to receive safety training for railroad/airport work. ☐ Follow provisions of applicable Geosyntec HS Procedures, below: ***Geosyntec Procedure(s):*** *HS-310-Helicopter Safety, HS 311-General Aviation (Small Aircraft) Safety*
☐	**TRAFFIC/VEHICLE HAZARDS RELATED TO HEAVY EQUIPMENT, CONSTRUCTION SITE ACTIVITIES**	☐ See Section B.7., "Construction, Heavy Equipment, Lift Equipment"

B.3. WATER/BOATING HAZARDS ☐ Applicable ☒ Not Applicable or Not Anticipated

B.4. FALL HAZARDS ☐ Applicable ☒ Not Applicable, Not Anticipated

B.5. POWERED TOOLS, EQUIPMENT, MACHINERY ☒ Applicable ☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS:

Drilling subcontractor is responsible for safe use of any power tools. Gloves and safety glasses must be worn when using power tools. Drilling subcontractor is responsible for potential use of generator and compressor including following safe fueling practices.

☒	**POWERED HAND TOOLS** ☒ Battery-operated ☒ Electric-powered, 120v/240v ☒ Fuel-powered ☐ Pneumatic ☐ Powder-actuated Hazards: Eye/hand/body injury, fuel-related hazards, Inhalation hazards, noise, sparks, heat, fire hazard, electrical hazards	☒ For all power tools: • Inspect tools to ensure safe operating condition before each use. • Use tool in accordance with manufacturer's specifications. • Ensure guards are in place and no hazardous equipment modifications. • Use PPE or other safety practices, as appropriate, for eye/hearing/hand/head/body protection. • Provide training or verify operator competency for use of power tool. • Stay clear of hazard zone, "line of fire," when working near where power tools are used. • For spark/heat generating tool, control fire hazards, segregate combustible/flammable materials. • Use vise/clamp/work bench or other appropriate means to hold/secure the work piece. ☐ Use respirators, ventilation, wet methods, other appropriate means to control inhalation hazard. ☒ See fuel-safety practices in Section B.13., "Commercial Chemical Products." ☒ For electrical hazards, see Section B.8., "Electrical Hazards". ***Geosyntec Procedure(s):*** *HS-109-Hearing Conservation, HS-113-Personal Protective Equipment, HS-121-Electrical Safety, HS-503-Powered Hand Tools, Others as applicable*

☒	**OPERATION OF EQUIPMENT/MACHINERY** ☒ Point-of-operation hazards ☒ Pinch points, moving parts ☒ 'Struck-by,' 'caught between' ☒ Hot surfaces, heat ☒ Extension cords, flexible wire ☒ Fuel related (gas or liquid) ☒ Hydraulic pressure ☐ Pneumatic pressure ☒ Kinetic, stored energy ☒ Noise ☒ Emissions, discharge gases ☐ Working at heights, falls ☒ Lifting, repetitive motion ☐ Illumination ☒ Electrical	☒ <u>General safety requirements for equipment, machinery:</u> • Arrange worksite for safe access to equipment/machinery. • Use equipment/machinery in accordance with manufacturer's use and safety instructions. • Ensure point-of-operation, mechanical power transmission, other moving parts are guarded with protective devices; do not override interlocks, guards, protective devices. • Secure long hair/loose clothing/hanging jewelry near moving/rotating parts. • Heed warning signs/labels, keep safe distance; avoid locations of "struck by" and "caught between" hazards. • Implement lockout/tagout for repairs/adjustments/tooling changes. ☒ Use safe lifting practices for movement of heavy portable equipment ☒ Implement safe work practices for compressed air, pressurized systems (pneumatic/hydraulic), stored energy. ☐ For climbing/fall hazards associated with large equipment, see Section B.4., "Fall Hazards." ☒ For electrical hazards, see Section B.8., "Electrical Hazards." ☒ Operate fuel-powered equipment in well ventilated location. ☒ Use safe practices for fuels, see Section B.13., "Commercial Chemical Products." ***Geosyntec Procedure(s):*** *HS-109-Hearing Conservation, HS-113-Personal Protective Equipment, HS-119-Lockout/Tagout, HS-121-Electrical Safety, HS-503-Powered Hand Tools, Others as applicable*
☐	**LOCKOUT/TAGOUT OF HAZARDOUS ENERGY**	☐ Implement control-of-hazardous-energy practices (lockout/tagout), provide lockout/tagout locks and devices, training workers, designate "authorized" personnel, notify "affected" personnel. ***Geosyntec Procedure(s):*** *HS-119-Lockout Tagout*
☐	**WELDING, CUTTING, HOT WORK (GAS OR ARC)** UV/IR light-eye/skin burns, hot-work hazards, toxic welding fumes, compressed gases, electrical shock	☐ <u>General safe work practices:</u> • Hot work permit system to be implemented. • Operator properly protected (eye protection, clothing, apron, etc.). • Fire hazard controls (watcher, fire extinguisher, water, isolate combustibles). • Protect nearby personnel from hazardous UV, IR light (shielding, curtain). ☐ For gas welding/cutting, use gas cylinder safe practices (secured, upright, caps on when not in use, prevent Damage; never secure gas cylinders to metal bench used for arc welding). ☐ For arc welding, follow electrical safe work practices. See Section B.8., "Electrical Hazards." ☐ See Section B.13., "Commercial Chemical Products," for hazards of welding rods (toxic metals), welding gases. ***Geosyntec Procedure(s):*** *HS-511-Welding, Cutting and Other Hot Work*
☒	**COMPRESSED AIR, COMPRESSOR** (for compressed gases, see Section B.13., "Compressed Gases")	☒ Never direct nozzle toward body; do not use compressed air for cleaning clothes. ☐ If compressed air is used for cleaning, restrict pressure to 30 psi or below, equip nozzle with chip guard. ☒ Use eye protection. ☒ Ensure air tank, hoses, fittings are in good repair using factory fittings.
☒	**PORTABLE GENERATOR** Hazards: Electrical shock, carbon monoxide in exhaust, fuel-related fire, injury from mechanical hazards, lifting	☒ <u>Follow general safety practices for Operation of Equipment/Machinery (above), and as follows:</u> • Use in accordance with manufacturer's instructions. • Keep generator and work area dry. • Never use indoors, or near building air intake vents due to carbon monoxide hazard. • Provide for ventilation and/or air monitoring where hazardous accumulation of exhaust emissions is possible. • Use hearing protection in close proximity to operating generator, as needed. • Use power cords/extension cords specified by instructions. • Use ground-fault circuit interrupters (GFCIs) in accordance with manufacturer's instructions. • See Section B.8., "Electrical Hazards." • Shut down equipment before refueling. See safe practices for flammable/combustible liquids in Section B.13., "Commercial Chemical Products." ***Geosyntec Procedures:*** *HS-109-Hearing Conservation, HS-111-Air Monitoring, HS-115-Hazard Communication (for fuel), HS-121-Electrical Safety, Others as applicable*
☐	**PORTABLE HEATERS (electric or fuel powered)** Hazards: Electric-powered: Electrical shock, fires from hot surfaces. Fuel powered: Carbon monoxide in exhaust, fires from hot surfaces, fuel-related fires	☐ <u>Follow general safety practices for Operation of Equipment/Machinery (above), and as follows:</u> • Keep heater dry, and locate heater on level surface away from high traffic areas. • Never use fuel-powered heaters indoors, or near air intake vents, due to carbon monoxide hazard. • Provide for ventilation and/or air monitoring where hazardous accumulation of exhaust emissions is possible. • Keep combustible materials at least 3 feet from hot surfaces. • Do not use an extension cord or power strip to power an electric heater. • For electric heaters, See Section B.8., "Electrical Hazards." • Shut down fuel-powered equipment before refueling. See safe practices for flammable/combustible liquids and/or compressed gases in Section B.13., "Commercial Chemical Products." ***Geosyntec Procedures:*** *HS-111-Air Monitoring, HS-115-Hazard Communication (for fuel, HS-121-Electrical Safety, Others as applicable*

B.6. DRILLING ☒ Applicable ☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS:

Drilling subcontractor is responsible for operating drill rig safely. The fire extinguisher and emergency shut off will be identified prior to start of drilling. The emergency shut off will be tested before start of drilling. Special attention to overhead hazards will be taken when picking drilling location and positioning rig over boring location.

☒	**DRILLING** Hazards: Struck-by, run-over, caught between (pinch points), manual lifting, roll over, fluid leaks, fuel hazards, suspended equipment	☒ Follow safe work practices, as applicable: • Non-essential personnel to stay clear of drilling work zone when drill rig in operation. • Equipment inspected daily upon mobilization; maintained in good repair, backup alarms. • Leaks or defective safety equipment should be repaired before use. • Establish eye contact with operator and use hand signals prior to approaching near equipment. • PPE used near operating rig (eye/head/hearing/hand/foot protection, high visibility vests or equivalent). • Contractor inspects drill rig daily before use, verify daily that emergency stop is functional. • Drill rig to be equipped with operational emergency stop, equipment in good repair, machine guards in place, whip checks on high pressure lines. • Park personal/support vehicles in a location as to not obstruct travel lanes or other site operations. • Operators/helpers maintain safe distance from moving parts; secure loose hair, loose clothing, equipment. • Drill rigs will only be moved with masts lowered. • Max. safe slope for rig will be followed, drill rig leveled, appropriate blocking/cribbing as needed. • Use safety practices for refueling, fuel handling/storage/transport. • Spill equipment is available for fuel and hydraulic fluid leaks. • Verify mechanical lift/rigging equipment (cables, sheaves, boom, attachments) is in proper working order. • Ventilate and conduct air monitoring, as appropriate, when drilling indoors. ***Geosyntec Procedure(s):*** *HS-403-Drilling, Others as applicable*
☒	**IMPORTANT!** This work may/will include close proximity to overhead electric utility lines.	☒ Follow safe work practices per Section B.9., "Utility Related Hazards"

B.7. CONSTRUCTION, HEAVY EQUIPMENT, LIFT EQUIPMENT ☒ Applicable ☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS: Drilling subcontractor is responsible for operating drill rig safely. Geosyntec employees and subcontractors will be cognizant of pinch points, overhead hazards, and fluid leaks related to the drill rig.

☒	**HEAVY EQUIPMENT** Hazards: Struck-by, run-over, caught between (pinch points), roll over, fluid leaks, overhead hazards	☒ Follow general safe work practices for heavy equipment: • Trained/qualified persons operate all heavy equipment. • Do not get into a potential crush situation below or between equipment, or in an excavation. • No passengers on moving/operating equipment except where passenger seat/restraint is present. • Equipment inspected daily upon mobilization; maintained in good repair, backup alarms. • Leaks or defective safety equipment should be repaired before use. • Operators required to use seatbelts. • Maintain eye contact with operator and use hand signals prior to approaching near equipment. • High visibility vests for all personnel in construction vehicle work area, on-site roadways and travel lanes. • Maximum safe slope for each vehicle will be followed. • Personnel to stay clear of, or restrict access to, swing radius and travel path of equipment. • Spill equipment available for fuel and hydraulic fluid leaks. • Equipment locked, secured, brakes set, buckets/forks lowered, when not in use. • Park personal/support vehicles in a location as to not obstruct travel lanes or other site operations. • Mark temporary roadways clearly, provide berms/stop logs where needed. ***Geosyntec Procedure(s):*** *HS-504-Heavy Equipment, HS-132-Competent Persons*
☐	**CRANES** Hazards: - electrocution by overhead utility - injury in swing radius - injury from falling load - crane tipping over due to overbalancing, high winds, unstable ground, unsafe slope, bad placement of outriggers - injury from mechanical hazards	☐ In addition to general safety practices for heavy equipment (above), as applicable: • Only qualified persons operate cranes (certificate required). • Critical Lift Plan & Checklist prepared/executed (HS 506) prior to mobilization. • Equipment to be inspected prior to mobilization and daily by crane operator. • Crane operator will remain at the controls at all times during operation. • Crane operation must be performed under the direction of an appointed signal person at all times. • Communication between crane operator and signal person will be maintained through standard hand signals or voice communication equipment. • Keep area beneath suspended loads clear of personnel. • Rigging procedures – see Mechanical Lifting, Rigging, below. ***Geosyntec Procedure(s):*** *HS-506-Cranes, HS-132-Competent Persons*
☒	**MECHANICAL LIFTING, RIGGING** Applies to lifting by crane, truck-mounted boom rig (e.g. drill rig), mechanical/electrical hoist, similar equipment. Hazards: falling loads, personnel under suspended loads.	☒ In addition to general safety practices for heavy equipment and cranes (above), as applicable: • Coordinate lifting operations with competent person. • Do not exceed loading limits of lifting equipment; perform work in accordance with equipment load chart. • Slings, chains, rope, wire rope and related equipment used for lifting shall be maintained in good condition, and used in a manner as to protect from damage. • Rigging, wire rope and hoisting equipment will be inspected and maintained on a weekly basis.. • Ensure anchor points for winch or other lift device (such as davit arm) are engineered for intended use. ***Geosyntec Procedure(s):*** *HS-506-Cranes*

☐	**FORKLIFT** Hazards: Struck-by, run-over, overhead hazards, caught between (pinch points), roll over, fluid leaks.	☐ <u>In addition to general safety practices for heavy equipment (above), as applicable:</u> • Qualified operator, per established forklift training (certificate is required). • Equipment inspected daily and documented on Forklift Preoperational Inspection Checklist. • Do not exceed lifting load limits. • Forklift shall not be moved/driven with empty forks in raised position. • When not in use, forks lowered, brake set, controls in neutral, key removed. ***Geosyntec Procedure(s):*** *HS-505-Safe Operation of Forklifts, HS-132-Competent Persons*
☐	**AERIAL LIFTS**	☐ See Section B.4., "Fall Hazards" *Geosyntec Procedure(s): HS-509-Aerial Lifts*
☐	**TRENCHING/EXCAVATION** Hazards: Cave-in, hazardous atmosphere, structures & foundations, falls into excavations	☐ <u>Safe work practices when personnel will enter trenches/excavations:</u> • Activities under supervision/oversight of competent person, daily inspection. • Excavated materials placed at least 2' from trench sidewall. • Prevent water accumulation in trench. • Sloping & shoring for excavations ≥20' must be approved by a professional engineer. • Sloping/shoring/trench box for excavations ≥5' when persons enter trench/excavation. • Sloping/shoring/trench box for shallow (<5') excavations with cave-in hazard. • Workers in trenches to be within 25 feet of ladder or sloped entryway. • Excavations to be protected by perimeter fencing (not barricade tape), if potential for personnel to fall into. • If potential for atmospheric hazard, see Section B.10, "Confined Space Entry, Hazardous Enclosed Spaces" ***Geosyntec Procedure(s):*** *HS-402-Excavation and Trenching, HS-132-Competent Persons*
☒	**IMPORTANT!** This work may/will include close proximity to overhead and/or underground utility lines.	☒ Follow safe work practices per Section B.9., "Utility Related Hazards"
☐	**DEMOLITION**	☐ Develop/implement demolition safety plan. ***Geosyntec Procedure(s):*** *HS-132-Competent Persons*
☐	**BLASTING**	☐ Develop/implement blasting safety plan. ***Geosyntec Procedure(s):*** *HS-307-Blasting and Use of Explosives, HS-132-Competent Persons*
☐	**PUBLIC AT RISK, SITE SECURITY**	☐ During site operations, protect public (overhead protection, barriers, warning signs). ☐ During off hours, protect public with barriers, warning signs/lights, other measures as appropriate. ☐ Lock/secure hazardous materials and/or equipment.

B.8. ELECTRICAL HAZARDS ☒ Applicable ☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS:

Drilling subcontractor is responsible for safe use of any electrical equipment used by drilling subcontractor. Geosyntec personnel to be cognizant of electrical hazards associated with extension cords, wet locations, as well as emissions from the generator, and use precautions accordingly. See discussion on utilities for overhead and underground utility hazards.

☒	**BASIC ELECTRICAL HAZARDS TO SKILLED NON ELECTRICAL WORKERS** Equipment/tool use/operation, use of extension cords, working near electrical equipment. Hazards: Electrical shock, secondary hazards (falls, other injuries).	☒ <u>Follow safe work practices:</u> • Control water-related/wet-location hazards in a manner appropriate for the job tasks/equipment/tool. • Never touch electrical equipment if you are wet, or standing in water or on wet surfaces. • Use extension cords/power cords properly, prevent damage, take out of service if damaged. • Inspect tool/equipment/extension cords/power cords/welding cables before each use; do not use if damaged. • Use GFCI-protected outlet or portable GFCI in wet locations, outdoors, basements, concrete floors. • Ensure live parts are guarded, enclosures secure. • Enclosures, circuits properly labeled. ***Geosyntec Procedure(s):*** *HS-121-Electrical Safety*
☐	**HANDS-ON ELECTRICAL WORK BY ELECTRICAL WORKER/TECHNICIAN:** ☐ Voltage < 50 v ☐ Voltage 50-600v ☐ Voltage > 600v ☐ AC ☐ DC ☐ 3-phase ☐ Battery and/or solar power ☐ Capacitor/transformer	☐ <u>Implement electrical safe work practices pertaining to:</u> • Worker training/qualification (Level 1, Level 2, Level 3) • General electrical safe work practices, grounding, use of GFCIs • Safe work practices during diagnostics/troubleshooting, maintenance, repair • Safe design features for electrical equipment • Arc flash protection ***Geosyntec Procedure(s):*** *HS-121-Electrical Safety, HS-129-High Voltage Electricity Safety*
☐	**LOCKOUT/TAGOUT OF ELECTRICAL ENERGY**	☐ Implement control-of-hazardous-energy practices (lockout/tagout), provide lockout/tagout locks and devices, training workers, designate "authorized" personnel, notify "affected" personnel. ***Geosyntec Procedure(s):*** *HS-119-Lockout Tagout, HS-121-Electrical Safety*
☐	**IMPORTANT!** This work may/will include close proximity to electric utility lines.	☐ Follow safe work practices per Section B.9., "Utility Related Hazards"

B.9. UTILITY RELATED HAZARDS ☒ Applicable ☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS: Utility checklist to be completed and reviewed in the field prior to borehole advancement. Soft dig to 5 ft bgs prior to drilling.		
☒	**OVERHEAD, ABOVE-GROUND UTILITIES**	☒ Maintain proper clearance, employ other appropriate precautions for the conditions. ***Geosyntec Procedure(s):*** *HS-304-Overhead Electrical Lines*
☒	**UNDERGROUND UTILITIES**	☒ Confirm appropriate underground utility clearance procedures have been completed prior to ground penetrations, and employ other utility clearance/locator practices, as appropriate for conditions. ☒ Hand digging or vacuum post-holing within 5' of utility locations or other high risk condition.
B.10. CONFINED SPACE ENTRY, HAZARDOUS ENCLOSED SPACES	☐ Applicable	☒ Not Applicable, Not Anticipated
B.11. STORAGE OF BULK MATERIALS	☐ Applicable	☒ Not Applicable, Not Anticipated
B.12. INFECTIOUS / ALLERGENIC BIOHAZARDS	☒ Applicable	☐ Not Applicable, Not Anticipated
EXPLANATORY NOTES, CLARIFICATIONS: COVID-19 best practices should be utilized, including social distancing protocols. See COVID-19 Addendum.		
☒	☐ Wastewater, sewer ☐ Bird Guano ☐ Mold, fungi, Valley Fever ☐ Bloodborne pathogens ☒ Other (describe above)	☐ Low hazard - use basic hygiene practices, protective gloves, provide for hand washing. ☐ More severe hazard - add protective clothing, respirator/dust mask, decon, as appropriate. ☐ For human pathogens use "Universal Precautions" per Bloodborne Pathogen Program. ***Geosyntec Procedure(s):*** *HS-133-Bloodborne Pathogens*
B.13. COMMERCIAL CHEMICAL PRODUCTS	☒ Applicable	☐ Not Applicable, Not Anticipated
EXPLANATORY NOTES, CLARIFICATIONS: Isobutylene will be used to calibrate the PID. Gas cylinders will be used in a well ventilated area and stored upright. Drilling subcontractor is responsible for bringing SDS and proper spill kits for any chemicals brought by drilling subcontractor including gasoline, diesel fuel, and concrete. Small amounts of strong acids including HCl and HNO3 will be used as preservatives in bottle ware for analyses. Care will be taken by Geosyntec to avoid overfilling bottles and contacting acid with skin or clothing, and an eyewash bottle should be available at each sampling location (where acid-preserved containers are opened and closed) in case of eye contact with acid preservative. An eyewash bottle should be available when decontaminating as well.		
☒	**PRODUCTS REGULATED BY HAZARD COMMUNICATION STANDARD**	☒ Safety Data Sheets available, either on site or readily available within same work shift, containers labelled properly, workers trained/oriented on hazards ☒ For subcontractor use of chemical products, coordinate/discuss during safety meetings. ☐ Conduct air monitoring, as appropriate (see Part C, "Air Monitoring, Worker Exposure Monitoring").

☒	**COMPRESSED GAS (flammable or nonflammable)**	☒ Secure cylinders upright, caps on when not in use, handle with care, prevent damage. ☐ Propane cylinders not in use must be stored outdoors in cage or similar secure enclosure. ☐ Ensure acetylene cylinders NOT secured to steel arc welding bench. ☒ Store/use in a manner to prevent asphyxiation hazard. ☐ Segregate oxygen and fuel gases by distance (20') or barrier. ☐ Control ignition sources. ☐ "No smoking" signage at cylinder storage area for flammable gases. ☐ Use/store in a manner to control inhalation exposure hazards, PPE, air monitoring.
☒	**FLAMMABLE/COMBUSTIBLE LIQUIDS**	☒ Proper storage (flam. storage cabinets, other storage precautions). ☒ Use proper fuel safety can (metal fuel can preferred). ☒ Control ignition sources. ☒ Grounding and bonding where appropriate.
☒	**ACIDS, CAUSTICS, OTHER CORROSIVES**	☒ Handle with care, use appropriate eye/face/skin protection. ☒ Eyewash, deluge shower, drench hose, hand washing (with water), as appropriate.
☐	**TOXIC**	☐ For toxic substances, use/store in a manner to control exposure hazards (inhalation, ingestion, skin contact, skin absorption); use PPE as appropriate, conduct air monitoring as appropriate.
☒	**EMISSIONS FROM FUEL COMBUSTION, INDUSTRIAL PROCESSES** ☒ Gasoline ☒ Diesel ☐ Propane/Natural Gas ☐ Welding/cutting/hot work ☒ Vehicle/equipment exhaust ☐ Other	☒ Position outdoor personnel upwind of exhaust source. ☐ Use blowers, fans to provide fresh air to work area and dissipate atmospheric hazards. ☐ Use respiratory protection for high levels of smoke, exhaust particulates, soot. ☒ Conduct air monitoring as appropriate (see Part C, "Air Monitoring").
☐	**OTHER HAZARDS**	☐ Describe other hazardous substances and safety measures under "Explanatory Notes, Clarifications," above.
☐	**CHEMICAL/HAZMAT STORAGE** Check this when jobsite requirements include special provisions for chemical storage.	☐ Chemical storage cabinet, cage, storage room, or similar. ☐ Ensure incompatible chemicals are segregated. ☐ Provide secondary containment. ☐ Locate special safety equipment near chemical storage

Geosyntec Procedures: *HS-115-Hazard Communication, HS-111-Air Monitoring, HS-112-Respiratory Protection, HS-113-Personal Protective Equipment, HS-114-Safety Training Programs, Others as applicable*

B.14. SITE CONTAMINANTS, CHEMICAL WASTES ☒ Applicable ☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS:

Potassium perchlorate and volatile organic compounds are present in Site groundwater due to past use in manufacturing processes on Site.

CHECK ALL THAT APPLY. Provide explanatory notes above.

☒ Soil/groundwater contaminants (historical release)	☐ Oxygen deficiency	☐ Corrosive, acids/caustics, strong irritants
☐ Recent release, known high concentrations	☐ Chlorinated volatile organic compounds (VOCs)	☐ Sulfides, hydrogen sulfide (H_2S)
☐ Former chemical disposal site, landfill	☒ BTEX, petroleum derived VOCs	☐ Cyanides, hydrogen cyanide (HCN)
☐ Urban fill, residual contaminants	☒ Fuel oils, petroleum, waste oil, lubricants	☐ Asbestos
☐ Containerized waste (drums, process equipment)	☐ Metals, metal compounds, metal dusts	☐ Lead paint
☐ Buried drums (known or potential)	☐ Elemental mercury	☐ Pesticides, herbicides, fungicides
☐ Large containers, potential for spills	☐ Polyaromatic hydrocarbons (PAHs)	☐ Sensitizers
☐ Contaminated building surfaces	☐ Polychlorinated biphenyls (PCBs)	☐ Radioactive contaminants
☐ Unexploded ordnance	☐ Potential for flammable vapors	☐ Other (see Explanatory Notes, above)
☐ Explosive dust	☐ Potential for flammable gas (methane)	

☐	**FOR WORK CONSISTING OF CLEANUP OPERATIONS, CORRECTIVE ACTIONS, PRELIMINARY INVESTIGATIONS at an "UNCONTROLLED HAZ. WASTE SITE" (per HAZWOPER, 29 CFR 1910.120), implement the following as applicable to the work:** - Implement site control plan via Exclusion Zone(s), Contaminant Reduction Zone(s) and Support Zone (aka EZ, CRZ, SZ) - Workers to be aware of and trained on hazards per OSHA Hazard Communication Standard. - Include site map/figure depicting work locations and other relevant site-specific information. - Site workers in EZ or CRZ to have OSHA 40-hour training, current 8-hour refresher, 3 days supervised field experience. - Site supervisor(s) required to have 8-hr. Supervisor training. - Site workers in EZ or CRZ to participate in Medical Monitoring program, as applicable. - Implement site-specific procedures for worker protection via engineering controls, work practices, personal protective equipment (PPE), air monitoring, decontamination procedures, spill containment, emergency preparedness and response. - Conduct air monitoring, as appropriate (see Part C, "Air Monitoring, Worker Exposure Monitoring"). **IMPORTANT:** Provide supplemental information to sufficiently detail site-specific procedures for the above elements, as appropriate for the work. ***Geosyntec Procedures:*** *HS-301-HAZWOPER, HS-108-Medical Monitoring Surveillance, HS-111-Air Monitoring, HS-112-Respiratory Protection, HS-113-Personal Protective Equipment, HS-114-Safety Training Programs, HS-115-Hazard Communication, HS-405-Drum Sampling, Others as applicable*
☒	**FOR SITE WITH CHEMICAL CONTAMINANTS OR WASTE BUT NOT REGULATED BY HAZWOPER** - Workers to be knowledgeable/aware of chemical hazards thru safety training/orientation and availability of hazard information - Implement controls to minimize worker exposure through engineering controls, work practices, PPE, as appropriate. - Conduct air monitoring/sampling to monitor/evaluate worker exposure, as applicable. ***Geosyntec Procedures:*** *HS-111-Air Monitoring, HS-112-Respiratory Protection, HS-113-Personal Protective Equipment, HS-114-Safety Training Programs, HS-115-Hazard Communication, Others as applicable*

☐	**OFF-SITE MIGRATION OF CONTAMINANTS**	☐ Implement controls to minimize hazard migration (dust suppression, covers, foam, etc.) ☐ Community/perimeter air monitoring to be conducted per perimeter air monitoring plan.
☐	**SPILL CONTAINMENT, CONTAINERS**	☐ Describe above any site-specific procedures for spill containment, container handling, as applicable. ***Geosyntec Procedures****: HS-406-Unknown Hazardous Waste Drum Handling*

B.15. RADIATION HAZARDS (Other than Sunlight) ☐ Applicable ☒ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS: One of the materials used and stored during past Shieldalloy operations contained radioactive material. Shieldalloy is currently decommissioning this material. All of the material has been moved to fenced off exclusion zones on-Site. It is not anticipated that Geosyntec personnel will need to come into contact with this material. Geosyntec personnel should not enter the fenced off exclusion zones.

☒	**IONIZING RADIATION**	Describe hazards & safety measures above in Explanatory Notes, Clarifications. Conduct exposure monitoring, as appropriate (see Part C, "Air Monitoring, Worker Exposure Monitoring"). ***Geosyntec Procedures:*** *HS-126-Radiation Safety Program, HS-128-Ionizing and Non-Ionizing Radiation*
☐	**NON-IONIZING RADIATION**	Describe hazards & safety measures above in Explanatory Notes, Clarifications. Conduct exposure monitoring, as appropriate (see Part C, "Air Monitoring, Worker Exposure Monitoring"). ***Geosyntec Procedures:*** *HS-128-Ionizing and Non-Ionizing Radiation*

B.16. HAZMAT/DANGEROUS GOODS SHIPPING/TRANSPORTATION ☐ Applicable ☒ Not Applicable, Not Anticipated

PART C – AIR MONITORING, WORKER EXPOSURE MONITORING

C.1. AIR MONITORING (Direct-Reading Instruments) ☒ Applicable ☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS:
Air monitoring will be performed with a PID during drilling activities. If levels higher than 1 ppm are detected, then the drilling crew will stand back from the borehole to allow for VOC concentrations to dissipate. Elevated PID readings are not anticipated for this Site.

☒	**AIR-TESTING PARAMETERS**	☒ VOCs, GASES ☒ PID, Lamp energy: 10.6 eV ☐ FID ☐ Carbon monoxide ☐ Hydrogen sulfide ☐ Oxygen (O_2)	☐ Flammable gas (LEL) ☐ Particulate (dust) ☒ Calibration kit for each parameter ☐ Other:
☐	**ACTION LEVELS FOR O2/LEL**	☐ Oxygen	≤19.5% - ventilate to raise O_2 to acceptable levels, or use Level B. ≥23.0% - ventilate to lower O_2 to acceptable levels, or use Level B and control fire hazards & ignition sources.
		☐ LEL	Confirm at least 12% oxygen is present to ensure accuracy of LEL readings. At <10% LEL - Continue working, continue to monitor LEL levels At ≥10% LEL- Immediately withdraw from area. Resume work ONLY after LEL readings reduced to <10%.

☒	**ACTION LEVELS FOR TOXICS** (sustained breathing zone concentrations)	**Parameters**	**Level D, Modified D***	**Use levels C or B*, as indicated below, OR take action to reduce breathing zone level to concentration acceptable for Level D*.**
		☒ VOCs	< 1.0 ppm	__ ppm to __ ppm: Level C (air purifying respirator) > __ ppm: Level B (air-supplied respirator)
		☐ Carbon Monoxide	< 35 ppm	≥35 ppm - Level B (air-supplied respirator)
		☐ Hydrogen Sulfide	< 10 ppm	≥10 ppm - Level B (air-supplied respirator)
		☐ Total Dust	< __ mg/m³	>__ mg/m³ - Level C (air-purifying respirator)
		☐		

		☐		

*** Levels of Protection:** **Level D** (standard work clothes, basic personal protective wear, no chemical protective clothing, no respiratory protection)
Modified Level D (chemical protective clothing in addition to standard work clothes, no respiratory protection)
Level C (air purifying respirator or dust mask, in addition to chemical protective clothing)
Level B or A (air supplied respirator, chemical protective suit; fully-encapsulating suit for Level A)

Geosyntec Procedures: *HS-111-Air Monitoring*

C.2. OTHER WORKER EXPOSURE MONITORING ☐ Applicable ☒ Not Applicable, Not Anticipated

PART D – APPROVALS, ACKNOWLEDGEMENTS

D.1. THA PREPARATION, REVIEW/APPROVAL SIGNATURES - THA typically prepared by project staff, reviewed/approved by Project Manager, Supervisor, qualified/knowledgeable designee, with support of HS personnel as deemed appropriate by the Project Manager.

	Printed Name	*Signature*	*Date*
THA PREPARED BY: (minimum one person)	Caroline Kellner	Caroline Kellner	8/4/2020
THA REVIEWED/ APPROVED BY: (minimum one person)	*Printed Name*	*Signature*	*Date*
	Matthew Mraw	Matthew Mraw	8/6/2020

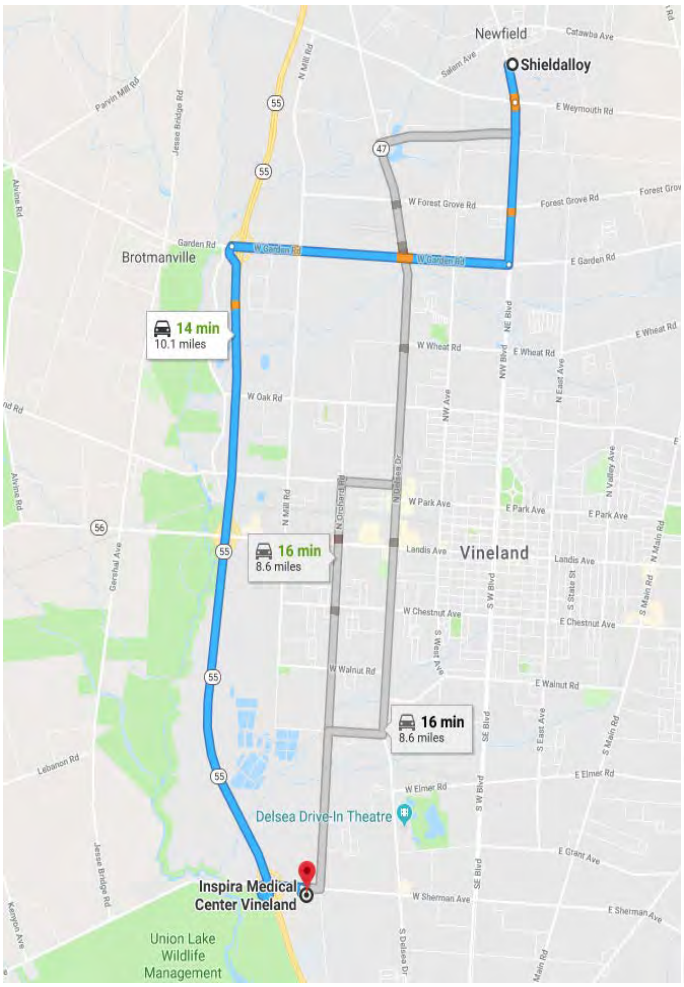
D.2. FIELD CREW ACKNOWLEDGEMENTS

GEOSYNTEC FIELD CREW
Please sign below to acknowledge you reviewed and understand this THA, participated in project safety briefing and had an opportunity to ask questions about the information herein.

Printed Name	Signature	Employee No.	Date

SUBCONTRACTOR'S FIELD CREW Please sign below to acknowledge that this THA was made available to you, and you had an opportunity to ask questions about the information herein.			
Printed Name	**Signature**	**Company Name**	**Date**

ROUTE TO HOSPITAL



Shieldalloy
35 West Blvd, Newfield, NJ 08344

Drive from W Garden Rd and NJ-55 S to Vineland

13 min (10.0 mi)

1. Head south on West Blvd toward W Weymouth Rd
   0.3 mi
2. Continue onto NW Blvd
   1.3 mi
3. Turn right onto W Garden Rd
   2.5 mi
4. Turn left to merge onto NJ-55 S
   5.3 mi
5. Take exit 29 for County 552 toward Bridgeton/S Vineland
   0.2 mi
6. Turn right onto W Sherman Ave (signs for County Road 552 E)
   0.4 mi

Drive to your destination

29 s (0.1 mi)

7. Turn right
   217 ft
8. Turn left
   Destination will be on the right
   285 ft

Inspira Medical Center Vineland

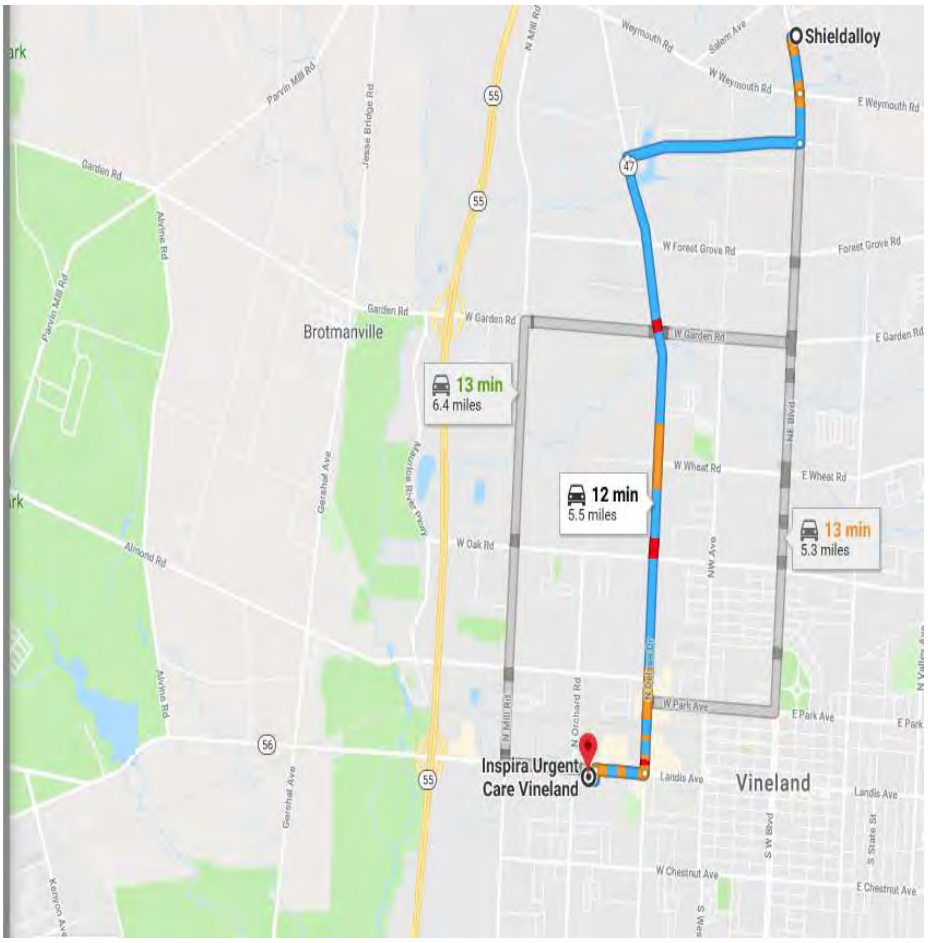
Inspira Medical Center Vineland
10.1 miles, 14 minutes
(856) 641-8000
1505 W Sherman Ave
Vineland, NJ 08360

ROUTE TO URGENT CARE FACILITY

Shieldalloy
35 West Blvd, Newfield, NJ 08344

- Take West Blvd to W Arbor Ave in Vineland
  - 1 min (0.6 mi)
- Head south on West Blvd toward W Weymouth Rd
  - 0.3 mi
- Continue onto NW Blvd
  - 0.3 mi
- Turn right onto W Arbor Ave
  - 2 min (1.2 mi)
- Follow N Delsea Dr
  - 7 min (3.6 mi)
- Turn left onto N Delsea Dr
  - 3.3 mi
- Turn right onto W Landis Ave
  - 0.3 mi
- Drive to your destination
  - 42 s (0.1 mi)

Inspira Urgent Care Vineland
1297 W Landis Ave, Vineland, NJ 08360



Inspira Urgent Care
5.5 miles, 12 minutes
(856) 507-8548
1297 W Landis Ave
Vineland, NJ 08360

Geosyntec consultants

TASK HAZARD ANALYSIS (Ver. 2, June 2015)

Geosyntec HS Procedures referenced herein are available on Geosyntec's H&S SharePoint site and should be consulted, as appropriate, per project-specific needs. This THA prepared per HS-106-Accident Prevention Program, HS-204-Task Hazard Analysis, and meets the requirements for a "Site-Specific Health and Safety Plan" per Geosyntec HS Procedures and regulations referenced herein (see Section B.14.).

PART A – SITE SAFETY PLAN

A.1. PROJECT/TASK INFORMATION

TASK:	Groundwater Sampling for Shieldalloy Metallurgical Corporation Site		
Project Name:	Shieldalloy Metallurgical Corporation OU3	**Project Number/Org:**	JR0241
Project Address:	35 West Boulevard Newfield, NJ		
Description of Task & Worksite:	Groundwater samples will be collected from shallow, intermediate, and deep groundwater wells following low-flow sampling protocol using a Grundfos pump. The Site was formerly a manufacturing facility but operations have ceased and the Site is now used for general warehousing/leasing, and administrative purposes. Groundwater is anticipated to be impacted with perchlorate and volatile organic compounds. All purge water will be containerized in closed top drums.		
Geosyntec Personnel	**Name**	**Desktop Office Phone**	**Cell Phone**
Site Lead/HS Officer	Jessica Evans	(609) 493-9003	(609) 379-9685
Project Manager	Seth Kellogg	(609) 493-9018	(732) 354-8463
Project Director	John Persico	(609) 493-9008	(609) 903-6227
HS Coordinator	Matt Mraw	(609) 493-9004	(609) 462-1198
Regional HS Mngr.	Mark Malchik	(978) 206-5777	(781) 392-5440
Corp. HS Director	Dale Prokopchak	804-665-2811	(804) 349-8067
Client Contact(s):	John Hunt	(484) 582-3519	(617) 957-5961
Subcontractor(s):	☒ Not Applicable ☐ Applicable, provide contact information below:		

A.2. EMERGENCY RESPONSE

Based on analysis of worksite factors, client/regulatory requirements, availability of emergency services.

Consider all Relevant Risk Factors & Response Procedures *(fire/explosion, medical, chemicals/spills, security, Site factors, weather, communications)*.

EXPLANATORY NOTES, CLARIFICATIONS:

In case of life-threatening emergency, immediately dial 911. Once the situation is stabilized, contact the Geosyntec project manager. Evacuation of the Site will be done through the exit on West Boulevard unless a closer exit is found available.

Available Means of Jobsite Emergency Communication/Alerting	☒ Verbal ☒ Cell Phone ☐ Land Line ☐ 2-Way Radio ☐ On-Site alarm/signal system ☐ Other:	
To Summon Emergency Services Police, Fire, Ambulance	☒ **DIAL 911**, for external responders ☐ **Other**:	
Other Emergency Contacts, as needed *(such as security, spill responder, utility):*	Gas Utility: PSE&G – 1800-436-7734 or 1800-880-7734 Electrical Utility: PSE&G: 1800-436-7734 or 1800-880-7734 Unknown Utility: 811	
Nearest Emergency Medical Services	Hospital Name: Inspira Medical Center Vineland Address: 1505 W Sherman Ave Vineland, NJ 08360 Phone #: (856) 641-8000	☒ See Attached Directions
For **Non-Emergency Urgent Care**	☒ Contact WorkCare, 24/7 at: 888-449-7787 ☒ Other: Inspira Urgent Care (856) 507-8548 1297 W Landis Ave, Vineland, NJ 08360	☒ See Attached Directions
Jobsite **Evacuation** Procedure, Rally Point, Place of refuge:	In case of evacuation, on-Site workers must meet at Site entrance on West Boulevard. Exit must be kept open for emergency vehicles.	
Special Emergency Equipment/Procedures	No special procedures	

IMPORTANT: After initial emergency response actions and incident stabilization, contact appropriate project personnel listed in Part A.1.

A.3. SUMMARY OF WORK STEPS, HAZARDS, CONTROLS

Based on **PART B, "HAZARD ANALYSIS,"** and worksite/client/project factors.

Task 1 – Travel to Site

Geosyntec travels to the Site and arrives at 35 West Boulevard.

Task 2- Check-in and initial setup of work zone

Geosyntec conducts tailgate safety meeting and sections off an area for calibration/staging.

Task 3 Equipment Preparation

Geosyntec calibrates the PID using isobutylene span cal gas. Geosyntec calibrates the YSI sonde using calibration standard solutions. Spent calibration fluid and spring water is contained in a 5-gallon bucket and disposed of with decon fluid and purge water (See Task 6). An equipment blank is taken.

Task 4 – Initial Water Level Measurements

At each of the monitoring wells, Geosyntec opens the manhole/stickup with hand tools and collects a water level measurement using a water level meter. The depth to bottom is also measured. The water level meter is deconned between each well (See Task 7)

Task 5 – Purge and sample monitoring wells

The Grundfos pump is prepared for groundwater purging and sampling. Tubing is cut to size and hooked up to the Grundfos pump. The Grundfos pump control box is set up, and the pump is lowered to the sampling interval in the well. At each well, groundwater is extracted through the Grundfos pump and purged into a 5-gallon bucket staged at the monitoring well after running through the flow-through cell of the YSI sonde. Once water quality parameters are stabilized, the flow-through cell is removed and groundwater samples are collected for analyses.

Task 6 – Purge water containerization

Purge water in 5-gallon buckets is transferred to and containerized in drums. The drums are sealed, labelled with a pending analysis drum label and stored on Site until pickup.

Task 7 – Equipment Decontamination

Equipment exposed to groundwater is deconned with Alconox solution and distilled water. Decon fluid is drummed with purge water.

Task 8 – Sample Transport Prep

Groundwater samples are packed in coolers on ice and prepared for either shipment or pick up by the laboratory. The chain of custody is completed.

Task 9 –Demoblization

Manhole covers are replaced, stick-up risers are closed and locked, and cones are removed. Calibrated equipment is cal-checked. All equipment is packed into the field vehicle. Geosyntec notifies project manager that the work was completed and leaves Site.

Task 10 – Travel off Site

Geosyntec travels off Site.

Safety "Key Words or Phrases"

- Driving safety (Task 1, 10)
- Pinch points (Task 2-9)
- Air monitoring (Task 2-9)
- Eye protection (Task 2-9)
- Foot protection (Task 2-9)
- Hand protection (Tasks 2-9)
- Heavy lifting (Task 2, 3, 5, 6, 7, 8, 9)
- Electrical safety (Task 3, 5, 9)
- Compressed gases (Task 3, 9)
- Exposure to contaminants (Task 4, 5, 6, 7, 8, 9)
- Exposure to corrosives (Task 5, 7, 8)

For Hazard Control Measures, See Parts B and C, below.

A.4. H&S EQUIPMENT LIST

List worksite equipment for worker protection; provide details in Explanatory Notes, Clarifications.

EXPLANATORY NOTES, CLARIFICATIONS: High-vis vest, hard-toed boots, and safety glasses must be worn at all times by on-Site personnel. A hard hat must be worn at all times while on Site, but is not needed at the off-Site Farm Parcel or other off-Site locations. Nitrile gloves must be worn when handling groundwater, decon fluids, and equipment exposed to groundwater. Geosyntec will have a first aid kit, emergency eyewash, and fire extinguisher on hand. Sun screen and an easy-up tent will be used when weather conditions warrant their use. The sampling crew will mark out the monitoring wells with traffic control devices such as cones or similar so that enough room is provided for the sampling crew to operate. A PID will be used to monitor air quality when monitoring wells are opened. Used PPE will be disposed by Geosyntec.

☒	**ROUTINE PPE**	☒ Standard work clothes appropriate for task ☒ Hard-toed boots/shoes ☒ Hardhat ☒ Safety glasses	☒ Work gloves appropriate for task ☐ Noise/hearing protection ☒ High-visibility/reflective vest ☐ Ice creepers (boot attachments)
		☒ Basic PPE for protection from low-hazard chemical contact & dust (nitrile gloves, Tyvek suit, dust mask, boot covers).	
☒	**ROUTINE H&S EQUIPMENT/GEAR**	☒ First Aid Kit ☒ Fire extinguisher ☒ Emergency eyewash bottle(s) ☒ Insect control (repellant, wasp spray, other) ☐ Caution tape	☒ Sun protection (sunscreen, shade canopy, other) ☒ Project-supplied drinking water and/or hygiene facilities ☒ Poison ivy skin wash (Technu or similar) ☒ Vehicle emergency kit (flares, lights, reflective device) ☒ Traffic control warning devices (cones, or similar)
		☐ Other:	

☐	**NON-ROUTINE PERSONAL PROTECTIVE EQUIPMENT (PPE)** (Indicate specific types of PPE in Explanatory Notes, Clarifications)	☐ Goggles and/or face shield ☐ Chemical protective gloves ☐ Coveralls (Tyvek, or other) ☐ Outer boots, boot covers	☐ Disposable n-95 dust mask ☐ Half-face respirator (APR), cartridges ☐ Full-face respirator (APR), cartridges ☐ Personal flotation device	☐ Fire retardant clothing ☐ Arc Flash Protection ☐ Electrical-Hazard-rated boots, gloves ☐ Personal fall apparatus
		☐ Other:		
☐	**SPECIAL HAZARD CONTROLS**	☐ Portable GFCI	☐ Lockout/tagout equipment	☐ Ventilation equipment (fan, blower)
		☐ Eyewash - 15 min. flow	☐ Emergency deluge shower	☐ Air horn, alarm
		☐ Other:		
☒	**DECON, PPE DISPOSAL**	☒ Receptacle for disposable PPE	☐ Hand washing provisions	☐ Decon solution, related supplies
		☐ Other:		
☒	**AIR MONITORING EQUIPMENT, OTHER EQUIPMENT FOR WORKER EXPOSURE TESTING**	List equipment/devices to be brought to worksite; Use in accordance with procedures in Part C: PID		

PART B – HAZARD ANALYSIS and CONTROLS *Complete Section B.1., then subsequent sections as applicable to the task(s).*

B.1. ROUTINE HAZARD PREPAREDNESS **This section required for all tasks.**

Explanatory Notes, Clarifications: The monitoring wells are spread out across 67 acres. Caution will be exercised driving to wells, and personnel will maintain awareness of their surroundings. Insect repellant spray and/or long sleeves are recommended as biting insects and poisonous plants may be encountered. Insect repellant spray will be made available. High-vis vest, hard-toed boots, and safety glasses must be worn at all times. Nitrile gloves must be worn when handling groundwater, decon fluids, and equipment exposed to groundwater. Good housekeeping must be maintained in the work zone to minimize trip hazards. Proper lifting techniques must be followed when moving sampling equipment and coolers. Anything greater than 50 lbs requires a two-person lift. Cut-resistant protective gloves must be worn when cutting plastic sheeting and tubing. Tubing cutters should be used when cutting tubing. Protective gloves should be worn when lifting heavy equipment, opening or closing drum lids, and opening manhole covers. Sampling crews must adhere to the 30/30 rule for lightning and must seek shelter in a field vehicle. Crews must monitor for heat stress and drink plenty of fluids throughout the course of the day. Seek shade when needed and set up a canopy over the monitoring well if warranted due to high temperatures. If work is to be performed alone, the sampler must check in with the project manager at the start of the day, mid-day, and at the end of the day.

General Safety, Wellness, Preparedness – Delineate Site-specific HS aspects, as appropriate, in "Explanatory Notes, Clarifications," above.

☒ **General premises** hazards - housekeeping, rough terrain, trip hazards, steep slope, remote location.
☒ **Weather/climate-related hazards** – heat stress/cold stress measures, sun screen, severe weather shelter/refuge, "30/30 rule" for lightning
☒ **Plant/Insect/Animal Hazards** - Precautions: poison ivy wash; insect repellant; check for ticks; hornet nest spray; animal precautions.
☒ **Worksite traffic hazards** – Implement measures to protect personnel (high visibility/reflective clothing, on-person lighting, traffic control measures).
☐ **Illumination hazards/night work** - Illuminate work areas and/or access routes, use reflective/hi-visibility clothing or on-person lighting, as appropriate.
☒ **Lifting, manual material handling** – use proper lifting procedures, seek help for >50 lbs.

Geosyntec Procedures: *HS-124-Heat Stress, HS-125-Cold Stress, HS-127-Ticks, HS-208-Housekeeping, HS-210-Walking and Working Surfaces, HS-401-Back Injury Prevention, HS 517 Traffic Safety*

Routine Personal Protection – Delineate Site-specific HS aspects, as appropriate, in "Explanatory Notes, Clarifications," above.

☐ **Head protection from overhead hazards** - Wear hardhat or "bump cap" as appropriate for hazard.
☒ **Hand protection** - Wear protective work gloves appropriate for the hazard and work tasks.
☒ **Eye protection** - Wear safety glasses (with side shield or wrap around, either clear or shaded for sun protection), or other appropriate eye protection.
☒ **Foot protection, rough terrain** - Wear work boots/shoes with hard toes, ankle support, puncture resistance, traction, as appropriate for conditions.
☐ **Hearing protection** – use earplugs, earmuffs (or both) as appropriate for conditions; at a minimum where noise levels exceed 85dBA.
☐ **Dust, unsanitary conditions** – For general protection against minimal non-specific hazards, use protective clothing and/or disposable dust mask, as needed.

Geosyntec Procedures: *HS-109-Hearing Conservation, HS 112-Respiratory Protection, HS-113-Personal Protective Equipment, HS-207-Working Alone, HS-105-Driver and Vehicle Safety*

Tools, Equipment, Machinery – Delineate Site-specific HS aspects, as appropriate, in "Explanatory Notes, Clarifications," above.

☒ **Manual hand tools -** proper tool for the job, maintain in good condition, use vise/clamp to hold work piece, proper follow through, stay clear of "line of fire."
☒ **Knives, cutting tools -** Utility/folding/collapsible knives and fixed open-bladed knives/cutting tools are *not* permitted, unless specifically authorized. Cutting tools with automatically-retracting blades, or with enclosed/guarded blades are permitted. See HS-502-*Manual Hand Tools* for additional Information.
☐ ***Working near*** **powered tools/equipment/machinery** – safe distance, heed warning signs, stay out of "line of fire," use PPE (for eye/hearing/dust protection).
☐ ***Operation/use of*** **powered tools/equipment/machinery – See Section B.5.**

HS-502-Manual Hand Tools

Security – Delineate Site-specific HS aspects, as appropriate, in "Explanatory Notes, Clarifications," above.

☐ **High crime, urban** – Use appropriate measures for personal security (such as buddy system, security service, work scheduling, other measures)
☒ **Working alone** - Establish "check in" procedure with supervisor/project manager.

Geosyntec Procedures: *HS-207-Working Alone*

Routine Driving Hazards – **Delineate Site-specific HS aspects, as appropriate, in "Explanatory Notes, Clarifications," above.**

☒ **Routine work travel** - Use routine safe/defensive driving practices (seat belts, safe speeds, eyes ahead, no tailgating, limit distractions, safe cell phone use, no texting, clear windows, account for weather/road conditions, adequate sleep, other measures as appropriate).

☒ **Unfamiliar location** - Plan travel route before driving (assemble maps, enter destination in GPS).

☒ **Long Distance or During Sleep Hours** – Minimize fatigue: rest breaks, light snacks (avoid heavy meals), stay hydrated, fresh air, no loud music, clean windshield.

☒ **Unfamiliar vehicle** – Become familiar with vehicle operational controls and handling characteristics before operating vehicle.

Geosyntec Procedures: *HS-105-Driver and Vehicle Safety*

B.2. SPECIAL DRIVING/TRAFFIC/TRANSPORTATION HAZARDS	☐Applicable	☒ Not Applicable, Not Anticipated
B.3. WATER/BOATING HAZARDS	☐ Applicable	☒ Not Applicable or Not Anticipated
B.4. FALL HAZARDS	☐ Applicable	☒ Not Applicable, Not Anticipated
B.5. POWERED TOOLS, EQUIPMENT, MACHINERY	☒ Applicable	☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS: A generator will be used to provide electricity to run the Grundfos pumps.

☐	**POWERED HAND TOOLS** ☐ Battery-operated ☐ Electric-powered, 120v/240v ☐ Fuel-powered ☐ Pneumatic ☐ Powder-actuated Hazards: Eye/hand/body injury, fuel-related hazards, Inhalation hazards, noise, sparks, heat, fire hazard, electrical hazards	☐ For all power tools: • Inspect tools to ensure safe operating condition before each use. • Use tool in accordance with manufacturer's specifications. • Ensure guards are in place and no hazardous equipment modifications. • Use PPE or other safety practices, as appropriate, for eye/hearing/hand/head/body protection. • Provide training or verify operator competency for use of power tool. • Stay clear of hazard zone, "line of fire," when working near where power tools are used. • For spark/heat generating tool, control fire hazards, segregate combustible/flammable materials. • Use vise/clamp/work bench or other appropriate means to hold/secure the work piece. ☐ Use respirators, ventilation, wet methods, other appropriate means to control inhalation hazard. ☐ See fuel-safety practices in Section B.13., "Commercial Chemical Products." ☐ For electrical hazards, see Section B.8., "Electrical Hazards". ***Geosyntec Procedure(s):*** *HS-109-Hearing Conservation, HS-113-Personal Protective Equipment, HS-121-Electrical Safety, HS-503-Powered Hand Tools, Others as applicable*
☐	**OPERATION OF EQUIPMENT/MACHINERY** ☐ Point-of-operation hazards ☐ Pinch points, moving parts ☐ 'Struck-by,' 'caught between' ☐ Hot surfaces, heat ☐ Extension cords, flexible wire ☐ Fuel related (gas or liquid) ☐ Hydraulic pressure ☐ Pneumatic pressure ☐ Kinetic, stored energy ☐ Noise ☐ Emissions, discharge gases ☐ Working at heights, falls ☐ Lifting, repetitive motion ☐ Illumination ☐ Electrical	☐ General safety requirements for equipment, machinery: • Arrange worksite for safe access to equipment/machinery. • Use equipment/machinery in accordance with manufacturer's use and safety instructions. • Ensure point-of-operation, mechanical power transmission, other moving parts are guarded with protective devices; do not override interlocks, guards, protective devices. • Secure long hair/loose clothing/hanging jewelry near moving/rotating parts. • Heed warning signs/labels, keep safe distance; avoid locations of "struck by" and "caught between" hazards. • Implement lockout/tagout for repairs/adjustments/tooling changes. ☐ Use safe lifting practices for movement of heavy portable equipment ☐ Implement safe work practices for compressed air, pressurized systems (pneumatic/hydraulic), stored energy. ☐ For climbing/fall hazards associated with large equipment, see Section B.4., "Fall Hazards." ☐ For electrical hazards, see Section B.8., "Electrical Hazards." ☐ Operate fuel-powered equipment in well ventilated location. ☐ Use safe practices for fuels, see Section B.13., "Commercial Chemical Products." ***Geosyntec Procedure(s):*** *HS-109-Hearing Conservation, HS-113-Personal Protective Equipment, HS-119-Lockout/Tagout, HS-121-Electrical Safety, HS-503-Powered Hand Tools, Others as applicable*
☐	**LOCKOUT/TAGOUT OF HAZARDOUS ENERGY**	☐ Implement control-of-hazardous-energy practices (lockout/tagout), provide lockout/tagout locks and devices, training workers, designate "authorized" personnel, notify "affected" personnel. ***Geosyntec Procedure(s):*** *HS-119-Lockout Tagout*
☐	**WELDING, CUTTING, HOT WORK (GAS OR ARC)** UV/IR light-eye/skin burns, hot-work hazards, toxic welding fumes, compressed gases, electrical shock	☐ General safe work practices: • Hot work permit system to be implemented. • Operator properly protected (eye protection, clothing, apron, etc.). • Fire hazard controls (watcher, fire extinguisher, water, isolate combustibles). • Protect nearby personnel from hazardous UV, IR light (shielding, curtain). ☐ For gas welding/cutting, use gas cylinder safe practices (secured, upright, caps on when not in use, prevent Damage; never secure gas cylinders to metal bench used for arc welding). ☐ For arc welding, follow electrical safe work practices. See Section B.8., "Electrical Hazards." ☐ See Section B.13., "Commercial Chemical Products," for hazards of welding rods (toxic metals), welding gases. ***Geosyntec Procedure(s):*** *HS-511-Welding, Cutting and Other Hot Work*
☐	**COMPRESSED AIR, COMPRESSOR** (for compressed gases, see Section B.13., "Compressed Gases")	☐ Never direct nozzle toward body; do not use compressed air for cleaning clothes. ☐ If compressed air is used for cleaning, restrict pressure to 30 psi or below, equip nozzle with chip guard. ☐ Use eye protection. ☐ Ensure air tank, hoses, fittings are in good repair using factory fittings.

☒	**PORTABLE GENERATOR** Hazards: Electrical shock, carbon monoxide in exhaust, fuel-related fire, injury from mechanical hazards, lifting	☒ Follow general safety practices for Operation of Equipment/Machinery (above), and as follows: • Use in accordance with manufacturer's instructions. • Keep generator and work area dry. • Never use indoors, or near building air intake vents due to carbon monoxide hazard. • Provide for ventilation and/or air monitoring where hazardous accumulation of exhaust emissions is possible. • Use hearing protection in close proximity to operating generator, as needed. • Use power cords/extension cords specified by instructions. • Use ground-fault circuit interrupters (GFCIs) in accordance with manufacturer's instructions. • See Section B.8., "Electrical Hazards." • Shut down equipment before refueling. See safe practices for flammable/combustible liquids in Section B.13., "Commercial Chemical Products." ***Geosyntec Procedures:*** *HS-109-Hearing Conservation, HS-111-Air Monitoring, HS-115-Hazard Communication (for fuel), HS-121-Electrical Safety, Others as applicable*
☐	**PORTABLE HEATERS** **(electric or fuel powered)** Hazards: Electric-powered: Electrical shock, fires from hot surfaces. Fuel powered: Carbon monoxide in exhaust, fires from hot surfaces, fuel-related fires	☐ Follow general safety practices for Operation of Equipment/Machinery (above), and as follows: • Keep heater dry, and locate heater on level surface away from high traffic areas. • Never use fuel-powered heaters indoors, or near air intake vents, due to carbon monoxide hazard. • Provide for ventilation and/or air monitoring where hazardous accumulation of exhaust emissions is possible. • Keep combustible materials at least 3 feet from hot surfaces. • Do not use an extension cord or power strip to power an electric heater. • For electric heaters, See Section B.8., "Electrical Hazards." • Shut down fuel-powered equipment before refueling. See safe practices for flammable/combustible liquids and/or compressed gases in Section B.13., "Commercial Chemical Products." ***Geosyntec Procedures:*** *HS-111-Air Monitoring, HS-115-Hazard Communication (for fuel, HS-121-Electrical Safety, Others as applicable*

B.6. DRILLING ☐ Applicable	☒ Not Applicable, Not Anticipated
B.7. CONSTRUCTION, HEAVY EQUIPMENT, LIFT EQUIPMENT ☐ Applicable	☒ Not Applicable, Not Anticipated
B.8. ELECTRICAL HAZARDS ☒ Applicable	☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS:
Sampling crews must be cognizant of electrical hazards associated with extension cords and wet locations and use precautions accordingly.

☒	**BASIC ELECTRICAL HAZARDS TO SKILLED NON ELECTRICAL WORKERS** Equipment/tool use/operation, use of extension cords, working near electrical equipment. Hazards: Electrical shock, secondary hazards (falls, other injuries).	☒ Follow safe work practices: • Control water-related/wet-location hazards in a manner appropriate for the job tasks/equipment/tool. • Never touch electrical equipment if you are wet, or standing in water or on wet surfaces. • Use extension cords/power cords properly, prevent damage, take out of service if damaged. • Inspect tool/equipment/extension cords/power cords/welding cables before each use; do not use if damaged. • Use GFCI-protected outlet or portable GFCI in wet locations, outdoors, basements, concrete floors. • Ensure live parts are guarded, enclosures secure. • Enclosures, circuits properly labeled. ***Geosyntec Procedure(s):*** *HS-121-Electrical Safety*
☐	**HANDS-ON ELECTRICAL WORK BY ELECTRICAL WORKER/TECHNICIAN:** ☐ Voltage < 50 v ☐ Voltage 50-600v ☐ Voltage > 600v ☐ AC ☐ DC ☐ 3-phase ☐ Battery and/or solar power ☐ Capacitor/transformer	☐ Implement electrical safe work practices pertaining to: • Worker training/qualification (Level 1, Level 2, Level 3) • General electrical safe work practices, grounding, use of GFCIs • Safe work practices during diagnostics/troubleshooting, maintenance, repair • Safe design features for electrical equipment • Arc flash protection ***Geosyntec Procedure(s):*** *HS-121-Electrical Safety, HS-129-High Voltage Electricity Safety*
☐	**LOCKOUT/TAGOUT OF ELECTRICAL ENERGY**	☐ Implement control-of-hazardous-energy practices (lockout/tagout), provide lockout/tagout locks and devices, training workers, designate "authorized" personnel, notify "affected" personnel. ***Geosyntec Procedure(s):*** *HS-119-Lockout Tagout, HS-121-Electrical Safety*
☐	**IMPORTANT!** This work may/will include close proximity to electric utility lines.	☐ Follow safe work practices per Section B.9., "Utility Related Hazards"

B.9. UTILITY RELATED HAZARDS ☐ Applicable	☒ Not Applicable, Not Anticipated
B.10. CONFINED SPACE ENTRY, HAZARDOUS ENCLOSED SPACES ☐ Applicable	☒ Not Applicable, Not Anticipated
B.11. STORAGE OF BULK MATERIALS ☐ Applicable	☒ Not Applicable, Not Anticipated
B.12. INFECTIOUS / ALLERGENIC BIOHAZARDS ☐ Applicable	☒ Not Applicable, Not Anticipated
B.13. COMMERCIAL CHEMICAL PRODUCTS ☒ Applicable	☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS:
Isobutylene will be used to calibrate the PID. These gas cylinders will be used in a well ventilated area. The cylinders will be emptied outdoors after use. Geosyntec personnel will not travel with unemptied cylinders in the vehicle. Small amounts of strong acids including HCl and HNO3 will be used as preservatives in bottle ware for analyses. Care will be taken by Geosyntec to avoid overfilling bottles and contacting acid with skin or clothing, and an eyewash bottle should be available

at each sampling location (where acid-preserved containers are opened and closed) in case of eye contact with acid preservative. An eyewash bottle should be available when deconning as well.

☒	**PRODUCTS REGULATED BY HAZARD COMMUNICATION STANDARD**	☒ Safety Data Sheets available, either on Site or readily available within same work shift, containers labelled properly, workers trained/oriented on hazards ☐ For subcontractor use of chemical products, coordinate/discuss during safety meetings. ☐ Conduct air monitoring, as appropriate (see Part C, "Air Monitoring, Worker Exposure Monitoring").
☒	**COMPRESSED GAS (flammable or nonflammable)**	☐ Secure cylinders upright, caps on when not in use, handle with care, prevent damage. ☐ Propane cylinders not in use must be stored outdoors in cage or similar secure enclosure. ☐ Ensure acetylene cylinders NOT secured to steel arc welding bench. ☒ Store/use in a manner to prevent asphyxiation hazard. ☐ Segregate oxygen and fuel gases by distance (20') or barrier. ☐ Control ignition sources. ☐ "No smoking" signage at cylinder storage area for flammable gases. ☐ Use/store in a manner to control inhalation exposure hazards, PPE, air monitoring.
☐	**FLAMMABLE/COMBUSTIBLE LIQUIDS**	☐ Proper storage (flam. storage cabinets, other storage precautions). ☐ Use proper fuel safety can (metal fuel can preferred). ☐ Control ignition sources. ☐ Grounding and bonding where appropriate.
☒	**ACIDS, CAUSTICS, OTHER CORROSIVES**	☒ Handle with care, use appropriate eye/face/skin protection. ☒ Eyewash, deluge shower, drench hose, hand washing (with water), as appropriate.
☒	**TOXIC**	☒ For toxic substances, use/store in a manner to control exposure hazards (inhalation, ingestion, skin contact, skin absorption); use PPE as appropriate, conduct air monitoring as appropriate.
☒	**EMISSIONS FROM FUEL COMBUSTION, INDUSTRIAL PROCESSES** ☒ Gasoline ☐ Diesel ☐ Propane/Natural Gas ☐ Welding/cutting/hot work ☐ Vehicle/equipment exhaust ☐ Other	☒ Position outdoor personnel upwind of exhaust source. ☐ Use blowers, fans to provide fresh air to work area and dissipate atmospheric hazards. ☐ Use respiratory protection for high levels of smoke, exhaust particulates, soot. ☐ Conduct air monitoring as appropriate (see Part C, "Air Monitoring").
☐	**OTHER HAZARDS**	☐ Describe other hazardous substances and safety measures under "Explanatory Notes, Clarifications," above.
☐	**CHEMICAL/HAZMAT STORAGE** Check this when jobsite requirements include special provisions for chemical storage.	☐ Chemical storage cabinet, cage, storage room, or similar. ☐ Ensure incompatible chemicals are segregated. ☐ Provide secondary containment. ☐ Locate special safety equipment near chemical storage

Geosyntec Procedures: *HS-115-Hazard Communication, HS-111-Air Monitoring, HS-112-Respiratory Protection, HS-113-Personal Protective Equipment, HS-114-Safety Training Programs, Others as applicable*

B.14. SITE CONTAMINANTS, CHEMICAL WASTES ☒ Applicable ☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS:

Potassium perchlorate and volatile organic compounds are present in Site groundwater due to past use in manufacturing processes on Site.

CHECK ALL THAT APPLY. Provide explanatory notes above.

☒ Soil/groundwater contaminants (historical release)	☐ Oxygen deficiency	☐ Corrosive, acids/caustics, strong irritants
☐ Recent release, known high concentrations	☒ Chlorinated volatile organic compounds (VOCs)	☐ Sulfides, hydrogen sulfide (H_2S)
☐ Former chemical disposal Site, landfill	☐ BTEX, petroleum derived VOCs	☐ Cyanides, hydrogen cyanide (HCN)
☐ Urban fill, residual contaminants	☐ Fuel oils, petroleum, waste oil, lubricants	☐ Asbestos
☐ Containerized waste (drums, process equipment)	☐ Metals, metal compounds, metal dusts	☐ Lead paint
☐ Buried drums (known or potential)	☐ Elemental mercury	☐ Pesticides, herbicides, fungicides
☐ Large containers, potential for spills	☐ Polyaromatic hydrocarbons (PAHs)	☐ Sensitizers
☐ Contaminated building surfaces	☐ Polychlorinated biphenyls (PCBs)	☐ Radioactive contaminants
☐ Unexploded ordnance	☐ Potential for flammable vapors	☐ Other (see Explanatory Notes, above)
☐ Explosive dust	☐ Potential for flammable gas (methane)	

☐ **FOR WORK CONSISTING OF CLEANUP OPERATIONS, CORRECTIVE ACTIONS, PRELIMINARY INVESTIGATIONS at an "UNCONTROLLED HAZ. WASTE SITE" (per HAZWOPER, 29 CFR 1910.120), implement the following as applicable to the work:**

- Implement Site control plan via Exclusion Zone(s), Contaminant Reduction Zone(s) and Support Zone (aka EZ, CRZ, SZ)
- Workers to be aware of and trained on hazards per OSHA Hazard Communication Standard.
- Include Site map/figure depicting work locations and other relevant Site-specific information.
- Site workers in EZ or CRZ to have OSHA 40-hour training, current 8-hour refresher, 3 days supervised field experience.
- Site supervisor(s) required to have 8-hr. Supervisor training.
- Site workers in EZ or CRZ to participate in Medical Monitoring program, as applicable.

	- Implement Site-specific procedures for worker protection via engineering controls, work practices, personal protective equipment (PPE), air monitoring, decontamination procedures, spill containment, emergency preparedness and response. - Conduct air monitoring, as appropriate (see Part C, "Air Monitoring, Worker Exposure Monitoring"). **IMPORTANT:** Provide supplemental information to sufficiently detail Site-specific procedures for the above elements, as appropriate for the work. ***Geosyntec Procedures:*** *HS-301-HAZWOPER, HS-108-Medical Monitoring Surveillance, HS-111-Air Monitoring, HS-112-Respiratory Protection, HS-113-Personal Protective Equipment, HS-114-Safety Training Programs, HS-115-Hazard Communication, HS-405-Drum Sampling, Others as applicable*
☒	**FOR SITE WITH CHEMICAL CONTAMINANTS OR WASTE BUT NOT REGULATED BY HAZWOPER** - Workers to be knowledgeable/aware of chemical hazards thru safety training/orientation and availability of hazard information - Implement controls to minimize worker exposure through engineering controls, work practices, PPE, as appropriate. - Conduct air monitoring/sampling to monitor/evaluate worker exposure, as applicable. ***Geosyntec Procedures:*** *HS-111-Air Monitoring, HS-112-Respiratory Protection, HS-113-Personal Protective Equipment, HS-114-Safety Training Programs, HS-115-Hazard Communication, Others as applicable*
☐	**OFF-SITE MIGRATION OF CONTAMINANTS** — ☐ Implement controls to minimize hazard migration (dust suppression, covers, foam, etc.) ☐ Community/perimeter air monitoring to be conducted per perimeter air monitoring plan.
☐	**SPILL CONTAINMENT, CONTAINERS** — ☐ Describe above any Site-specific procedures for spill containment, container handling, as applicable. ***Geosyntec Procedures:*** *HS-406-Unknown Hazardous Waste Drum Handling*

B.15. RADIATION HAZARDS (Other than Sunlight) ☒ Applicable ☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS: One of the materials used and stored during past Shieldalloy operations contained radioactive material. Shieldalloy is currently decommissioning this material. All of the material has been moved to fenced off exclusion zones on-Site. It is not anticipated that Geosyntec personnel will need to come into contact with this material. Geosyntec personnel should not enter the fenced off exclusion zones.

☒	**IONIZING RADIATION**	Describe hazards & safety measures above in Explanatory Notes, Clarifications. Conduct exposure monitoring, as appropriate (see Part C, "Air Monitoring, Worker Exposure Monitoring"). ***Geosyntec Procedures:*** *HS-126-Radiation Safety Program, HS-128-Ionizing and Non-Ionizing Radiation*
☐	**NON-IONIZING RADIATION**	Describe hazards & safety measures above in Explanatory Notes, Clarifications. Conduct exposure monitoring, as appropriate (see Part C, "Air Monitoring, Worker Exposure Monitoring"). ***Geosyntec Procedures:*** *HS-128-Ionizing and Non-IonizingRadiation*

B.16. HAZMAT/DANGEROUS GOODS SHIPPING/TRANSPORTATION ☐ Applicable ☒ Not Applicable, Not Anticipated

PART C – AIR MONITORING, WORKER EXPOSURE MONITORING

C.1. AIR MONITORING (Direct-Reading Instruments) ☒ Applicable ☐ Not Applicable, Not Anticipated

EXPLANATORY NOTES, CLARIFICATIONS:
Air monitoring will be performed with a PID when opening monitoring wells. If levels higher than 1 ppm are detected, then the sampling crew will stand back from the well with the monitoring well left open to allow for VOC concentrations to dissipate. Elevated PID readings are not anticipated for this Site.

☒	**AIR-TESTING PARAMETERS**	☒ VOCs, GASES ☒ PID, Lamp energy: 10.6 eV ☐ FID ☐ Carbon monoxide ☐ Hydrogen sulfide ☐ Oxygen (O_2)	☐ Flammable gas (LEL) ☐ Particulate (dust) ☒ Calibration kit for each parameter ☐ Other:
☐	**ACTION LEVELS FOR O2/LEL**	☐ Oxygen	≤19.5% - ventilate to raise O_2 to acceptable levels, or use Level B. ≥23.0% - ventilate to lower O_2 to acceptable levels, or use Level B and control fire hazards & ignition sources.
		☐ LEL	Confirm at least 12% oxygen is present to ensure accuracy of LEL readings. At <10% LEL - Continue working, continue to monitor LEL levels At ≥10% LEL- Immediately withdraw from area. Resume work ONLY after LEL readings reduced to <10%.

		Parameters	Level D, Modified D*	Use levels C or B*, as indicated below, OR take action to reduce breathing zone level to concentration acceptable for Level D*.
☒	**ACTION LEVELS FOR TOXICS** (sustained breathing zone concentrations)	☒ VOCs	< 1.0 ppm	__ ppm to __ ppm: Level C (air purifying respirator) > __ ppm: Level B (air-supplied respirator)
		☐ Carbon Monoxide	< 35 ppm	≥35 ppm - Level B (air-supplied respirator)
		☐ Hydrogen Sulfide	< 10 ppm	≥10 ppm - Level B (air-supplied respirator)
		☐ Total Dust	< __ mg/m³	>__ mg/m³ - Level C (air-purifying respirator)
		☐		
		☐		

*** Levels of Protection:**
Level D (standard work clothes, basic personal protective wear, no chemical protective clothing, no respiratory protection)
Modified Level D (chemical protective clothing in addition to standard work clothes, no respiratory protection)
Level C (air purifying respirator or dust mask, in addition to chemical protective clothing)
Level B or A (air supplied respirator, chemical protective suit; fully-encapsulating suit for Level A)

Geosyntec Procedures: *HS-111-Air Monitoring*

C.2. OTHER WORKER EXPOSURE MONITORING ☐ Applicable ☒ Not Applicable, Not Anticipated

PART D – APPROVALS, ACKNOWLEDGEMENTS

D.1. THA PREPARATION, REVIEW/APPROVAL SIGNATURES - THA typically prepared by project staff, reviewed/approved by Project Manager, Supervisor, qualified/knowledgeable designee, with support of HS personnel as deemed appropriate by the Project Manager.			
THA PREPARED BY: (minimum one person)	*Printed Name*	*Signature*	*Date*
	Jessica Evans		April 15, 2019
THA REVIEWED/ APPROVED BY: (minimum one person)	*Printed Name*	*Signature*	*Date*
	John Persico		April 15, 2019
	Seth Kellogg		

D.2. FIELD CREW ACKNOWLEDGEMENTS

GEOSYNTEC FIELD CREW

Please sign below to acknowledge you reviewed and understand this THA, participated in project safety briefing and had an opportunity to ask questions about the information herein.

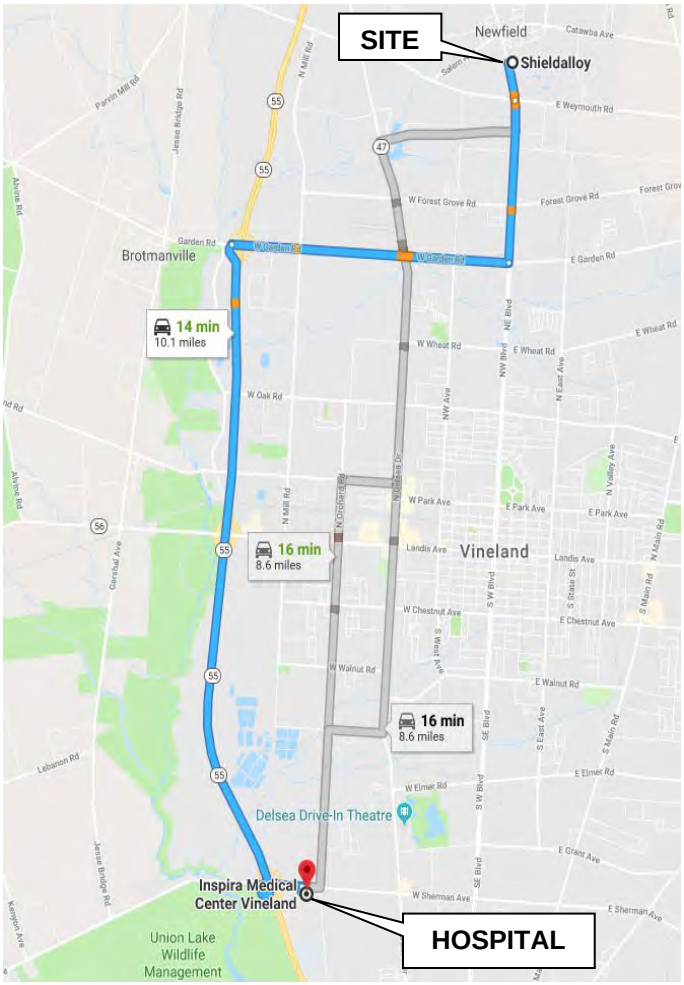
Printed Name	Signature	Employee No.	Date

SUBCONTRACTOR'S FIELD CREW

Please sign below to acknowledge that this THA was made available to you, and you had an opportunity to ask questions about the information herein.

Printed Name	Signature	Company Name	Date

ROUTE TO HOSPITAL



Shieldalloy
35 West Blvd, Newfield, NJ 08344

Drive from W Garden Rd and NJ-55 S to Vineland

13 min (10.0 mi)

1. Head south on West Blvd toward W Weymouth Rd — 0.3 mi
2. Continue onto NW Blvd — 1.3 mi
3. Turn right onto W Garden Rd — 2.5 mi
4. Turn left to merge onto NJ-55 S — 5.3 mi
5. Take exit 29 for County 552 toward Bridgeton/S Vineland — 0.2 mi
6. Turn right onto W Sherman Ave (signs for County Road 552 E) — 0.4 mi

Drive to your destination

29 s (0.1 mi)

7. Turn right — 217 ft
8. Turn left — 285 ft
   Destination will be on the right

Inspira Medical Center Vineland

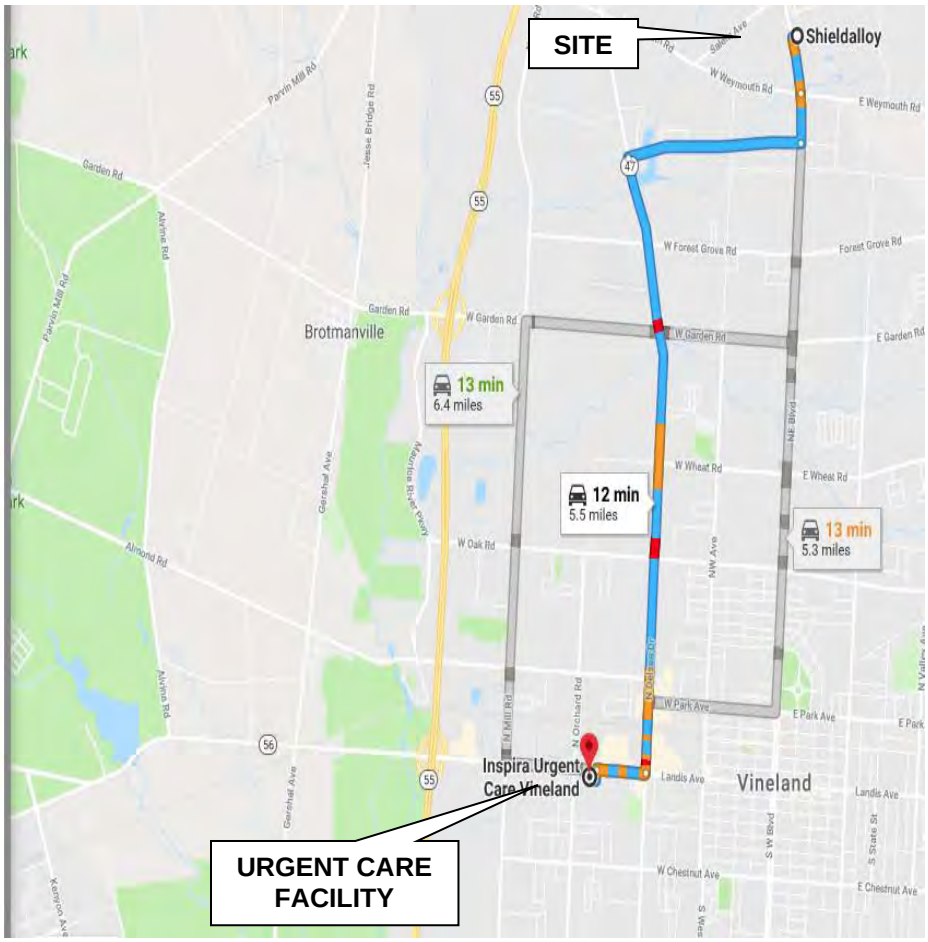
Inspira Medical Center Vineland
10.1 miles, 14 minutes
(856) 641-8000
1505 W Sherman Ave
Vineland, NJ 08360

ROUTE TO URGENT CARE FACILITY

Shieldalloy
35 West Blvd, Newfield, NJ 08344

- Take West Blvd to W Arbor Ave in Vineland
  - 1 min (0.6 mi)
  - Head south on West Blvd toward W Weymouth Rd
  - 0.3 mi
  - Continue onto NW Blvd
  - 0.3 mi
  - Turn right onto W Arbor Ave
  - 2 min (1.2 mi)
- Follow N Delsea Dr
  - 7 min (3.6 mi)
  - Turn left onto N Delsea Dr
  - 3.3 mi
  - Turn right onto W Landis Ave
  - 0.3 mi
- Drive to your destination
  - 42 s (0.1 mi)

Inspira Urgent Care Vineland
1297 W Landis Ave, Vineland, NJ 08360



Inspira Urgent Care
5.5 miles, 12 minutes
(856) 507-8548
1297 W Landis Ave
Vineland, NJ 08360

Appendix C: Summary of Chemical Hazards

Volatile Organic Compounds (VOCs)

Chlorinated VOCs are widely used as solvents in industrial operations such as degreasing, manufacturing, cleaning and dry cleaning, and are also present in household products and automotive fluids. They readily form vapors which can accumulate in indoor air spaces (i.e., via migration through the subsurface) and react with ozone to form sub-micron sized particles with the potential to cause adverse respiratory health effects. Free product releases (via surface or subsurface discharges or inadequate disposal) can migrate downward to significant depths and through fine-grained deposits to groundwater, and can persist as wide-scale sources of vapor plumes for long periods of time.

Several chlorinated hydrocarbons have been identified in soil, indoor air vapor, and groundwater at the Site including perchloroethylene (PCE), trichloroethylene (TCE), and 1,2-dichloroethane (DCA). The likely routes of exposure to chlorinated solvents include inhalation, ingestion and direct contact with the skin or eye. The toxicity of chlorinated solvents varies; many affect the central nervous system (CNS) and some are identified as carcinogens. PCE can affect the CNS and cause irritation of the skin, eyes, and upper respiratory tract. TCE can depress the CNS, affect kidneys, liver, and lungs and can cause rapid and irregular heartbeat. Toxic effects are increased when combined with alcohol, caffeine, and other drugs. DCA can cause CNS depression and damage to the liver, kidneys, heart, and digestive system. Eye contact with DCA can cause irritation and serious injury if not removed promptly. DCA and TCE are flammable liquids; the lower explosive limit (LEL) of both solvents are approximately 6% and their flash points are less than 100°F. PCE is not considered flammable. These chlorinated solvents are only slightly soluble in water.

Exposure levels will be maintained below OSHA PEL or NIOSH REL as shown in the table below.

Chemical Name	PEL[1]	REL[2]
1,2 DCA	50	1
TCE	100	Ca
PCE	100	Ca

[1] OSHA Permissible Exposure Limit (PEL) in parts per million
[2] Recommended Exposure Limit (REL); ACGIH Threshold Limit Value (TLV) in parts per million
Ca = Carcinogenic

Perchlorate

The perchlorate compound used in manufacturing processes on-Site is potassium perchlorate. Potassium perchlorate is a colorless crystal or white crystalline powder, and colorless when in

solution. Concentrated perchlorate is a strong oxidizer and can be a severe fire hazard. Perchlorate is a Site contaminant of concern in groundwater.

The primary exposure routes for perchlorate during work activities are ingestion of contaminated groundwater. Perchlorate is readily adsorbed after oral exposure and can migrate from the stomach and intestines to the bloodstream. The thyroid gland is the primary target of perchlorate toxicity in humans. Perchlorate can interfere with iodide uptake into the thyroid gland at high enough exposures, disrupting the functions of the thyroid and potentially leading to a reduction in the production of thyroid hormones (Agency for Toxic Substances and Disease Registry, 2008). Short-term exposure to high doses of ammonium-, sodium- or potassium- perchlorate may cause eye, skin and respiratory tract irritation, coughing, nausea, vomiting and diarrhea. Perchloric acid is corrosive to the eyes, skin and respiratory tract, and short-term exposure to high doses may cause sore throat, coughing, labored breathing, deep burns, loss of vision, abdominal pain, vomiting or diarrhea (National Institute for Occupational Safety and Health, 2013).

Radioactivity

Radioactive materials are known to have been present at the Site. Potentially radioactive soil and slag have been moved to a fenced off exclusion zone at the Site. It is not anticipated that Geosyntec personnel will come into contact with any radioactive materials during the work addressed by this HASP. Geosyntec personnel should not enter the exclusion zone.

Possible symptoms of exposure to radioactivity are: lacrimation, conjunctivitis, shortness of breath, cough, chest crackles, nausea, vomiting, skin burns, red blood cell casts in urine, albuminuria, and high blood urea nitrogen.

Geosyntec consultants

Appendix D: Air Monitoring

Applies to Task: ☒ ① ☒ ② ☐ ③ ☐ ④ ☐ ⑤ ☐ ⑥ ☐ ⑦ ☐ ⑧

☒ *Photoionization Detector (PID)*

Brand/Model No.: MiniRAE 3000___eV: 10.6_____

Monitoring Frequency: _Continuous_____

Breathing Zone Reading (ppm)	**Action**
___0__ to __1___	Level D PPE
Greater than __1__ _____	Stop work. Evacuate the area. If upon return, levels still exceed the action level, stop work and implement engineering controls.

Note: _____

☐ *Oxygen (O_2) Meter*

Brand/Model No.:_____

Monitoring Frequency:_____

Reading (%)	**Action**
Less than 19.5	Stop work. Evacuate the area.
19.5 to 23.5	Continue to work with caution.
Greater than 23.5	Stop work. Evacuate the area.

Note: _____

☐ *Explosimeter*

Brand/Model No.:_____

Monitoring Frequency:_____

Source (% LEL)

Reading	**Action**
1 to 10	Continue with caution.
Greater than 10	Stop work. Evacuate the area. If upon return, concentration still exceeds 10% LEL, ventilate until concentration is back to <10% LEL.

Note: _____

☐ *Flame Ionization Detector (FID)*

Brand/Model No.: _____

Monitoring Frequency: _____

Breathing Zone Reading (ppm)	**Action**
_____ to _____	Level D PPE
_____ to _____	Level C PPE
Greater than _____	Stop work. Evacuate the area. If upon return, levels still exceed _, stop work and implement engineering controls.

Note: _____

☐ *Chemical Detector Tube*

Brand/Model No.:

Monitoring Frequency:_____

Breathing Zone Reading (ppm)	**Action**
_____ to _____	Level D PPE
_____ to _____	Level C PPE
Greater than _____	Stop work. Evacuate the area. If upon return, levels still exceed _, stop work and implement engineering controls.

Note: _____

☐ *Other*

Brand/Model No.:_____

Monitoring Frequency:_____

Breathing Zone Reading	**Action**
_____ to _____	Level D PPE
_____ to _____	Level C PPE
Greater than _____	Stop work. Evacuate the area. If upon return, levels still exceed _, stop work and implement engineering controls.

Note: _____

Appendix E: Personal Protective Equipment

	Task ①	Task ②	Task ③	Task ④	Task ⑤	Task ⑥	Task ⑦	Task ⑧
Potential PPE Level per Task:	☒ D ☐ C	☒ D ☐ C	☐ D ☐ C	☐ D ☐ C	☐ D ☐ C	☐ D ☐ C	☐ D ☐ C	☐ D ☐ C

Modified Level D		***Level C***	
Equipment	***Material/Type***	***Equipment***	***Material/Type***
☒ Safety glasses	ANSI Z87.1-2010	☐ Full-face air-purifying respirator	Cartridge Type:
☒ Hard-toed boots	OSHA 1910.136	☐ Half-mask air-purifying respirator	Cartridge Type:
☐ Protective clothing	Fire Resistant (FR) Clothing	☐ Safety glasses	
☒ Hard hat*		☐ Hard-toed boots	
☒ Hearing protection*		☐ Protective clothing	
☒ High-visibility vest*	ANSI 107: Class 1	☐ Hard hat	
☐ Outer boots*		☐ Hearing protection*	
☒ Outer gloves*	Nitrile	☐ High-visibility vest*	
		☐ Outer boots*	
		☐ Outer gloves*	
		☐ Inner gloves*	

* PPE items may be downgraded (only with concurrence of SHSO and PM).

	Task ①	Task ②	Task ③	Task ④	Task ⑤	Task ⑥	Task ⑦	Task ⑧
Potential PPE Level per Task:	D C	D C	D C	D C	D C	D C	D C	D C

Appendix F: Safety Data Sheets

Included in this HASP	Chemical
☐	Acetone
☒	Alconox
☐	Ammonia
☐	Bentonite
☐	Diesel Fuel Oil No. 2-D
☐	Gasoline
☐	Helium
☐	Hexane
☐	Hydrochloric Acid
☐	Hydrogen
☒	Isobutylene Calibration Gas
☐	Isopropyl Alcohol
☐	KB-1
☐	Methane Calibration Gas
☐	Nitric Acid
☐	Permanganate
☐	Portland Cement
☐	Sulfuric Acid
☐	Other: _____
☐	Other: _____
☐	Other: _____
☐	Other: _____

Note: SDSs are presented on the following pages.

Geosyntec consultants | family of companies

Date: April 3, 2020

Revision: 3.1

Health & Safety

Field Work COVID-19 General Prevention Measures

Scope of this Document

The COVID-19 global pandemic has spread to essentially all geographic regions where Geosyntec has a presence. However, we are committed to protecting the health and safety of our employees while we continue to execute our essential work activities on behalf of clients.

To facilitate the safety and well-being of our employees while continuing field operations, the Corporate H&S Department has prepared these strategies to help employees minimize the risk of spreading or contracting COVID-19 during fieldwork operations. This information supplements other guidelines and communications already distributed via the Geosyntec COVID-19 SharePoint Portal HERE. All Geosyntec employees engaged in fieldwork must apply these prevention/mitigation strategies as appropriate and feasible for their work, as well as adhere to any applicable government mandates and client requirements, to minimize the risks of transmitting or contracting COVID-19.

The below measures are intended to provide guidance applicable to our most common field work situations at Geosyntec but may not suit every situation that may arise on your projects. We invite all staff to share their questions and ideas with Managers and Supervisors, Health and Safety Coordinators and Corporate Health and Safety Department.

All Corporate Health and Safety staff are available to assist you with COVID-19 safety solutions on your projects, and we will continue to update and improve these guidelines as we learn more and receive your feedback.

Risk Analysis

The COVID-19 pathogen can be transmitted from infected individuals (who may or may not be experiencing symptoms). So, all project/worksite locations and surrounding communities, and all coworkers and community members, represent a potential source of exposure for Geosyntec personnel. The virus is spread primarily through *inhalation* and *ingestion* of airborne respiratory droplets and aerosols containing the virus, and through *direct contact* with contaminated surfaces, so our risk-reduction guidelines are based on the core strategies of ***physical distancing (a.k.a. social distancing), personal hygiene*** and ***workspace sanitation***, and in certain high-risk situations ***personal protective equipment***.

Situation-Based Protection Strategies

1. Be On-the-Lookout for Symptoms

- Symptoms – the most common COVID-19 symptoms include fever, non-typical fatigue, dry cough, and shortness of breath; less-common symptoms include muscle aches/pains, gastrointestinal distress, and loss of taste or smell. In severe cases, *emergency warning signs requiring immediate medical attention* may include trouble breathing, persistent pain or pressure in the chest, confusion, inability to arouse, and bluish lips or face.
- Self-monitor for symptoms - all site personnel operating under Geosyntec are expected to self-monitor for symptoms consistent with COVID-19 (detailed above); if you feel unwell or show signs/symptoms of COVID-19, immediately isolate from other site personnel.

- On site - If you are on site and begin to experience symptoms stop working immediately, isolate from all other site personnel and contact the project manager (who will inform HR and the Branch Manager). Leave the site as soon as possible and follow Geosyntec company guidance, do not return to the site until approved by the project manager. The company also recommends you seek medical care from your own personal doctor or health care provider.
- Off Site/Work – If you begin experiencing symptoms while away from work DO NOT GO TO THE JOB SITE. Contact the project manager and follow Geosyntec company guidance. Do not return to the site until approved by the project manager. The company also recommends you seek medical care from your own personal doctor or health care provider.

For either of the above cases the Geosyntec HR & H&S Departments, in coordination with the project manager, will recommend appropriate follow-up measures regarding other project personnel. Project managers will need to make arrangements for replacement personnel if anyone is required to leave the site for an extended period of time.

- Coworker with symptoms – if a Geosyntec coworker, subcontractor, client or client contractor exhibits symptoms, or has presumptive or confirmed COVID-19, avoid close contact and implement safe work practices (delineated herein) as applicable. Contact the project manager, who will inform HR, H&S and the Branch Manager; the HR/H&S team, together with the project team, will evaluate risks and recommend appropriate response.
- Daily tailgate safety meetings – on a daily basis: communicate with on-site coworkers to reinforce COVID-19 prevention measures in general and those specific to the work, re-discuss symptoms to be on the lookout for, and confirm with each individual on the project team that they are not experiencing any possible COVID-19 symptoms.

2. Integrate Physical Distancing Strategies into all Field Work Activities and Meetings

- Interpersonal physical distancing – for all work activities, maintain a *minimum* distance of 2 meters/6 feet from all other field staff, visitors and general public when possible. Where physical distancing objectives are not workable, and alternatives are permissible under state/local requirements, utilize other protective strategies as applicable to the situation (such as more frequent hand washing, more frequent work area sanitization, use of disposable PPE, etc. – see the note below and Sections 3 & 8).
- Meetings - eliminate in-person meetings where possible; video meetings and conference calls are preferable; practice physical distancing when conducting onsite daily tailgate safety meetings, pre-work assessments, progress meetings, oversight observations of the work; where in-person meetings are necessary, limit the meeting to key individuals who absolutely need to attend; all attendees shall practice physical distancing—minimum of 2 m/6 ft between individuals.
- Indoor/enclosed spaces - minimize or eliminate time spent in a field trailer, and in similar indoor/enclosed work areas, particularly areas frequented by other individuals (coworkers, on-site personnel, general public); where possible, conduct work tasks and in-person meetings out-of-doors to reduce transmission of airborne disease agents.
- Social greetings - avoid hand shaking and other social greetings with direct contact or proximity to individuals within the physical distancing limits; greet coworkers at a distance. Do not pass items like paperwork/documentation, business cards, etc. between personnel.

Note: Physical distancing is the preferred method to control person-to-person transmission. However, in specific circumstances where the parameters described above cannot be properly maintained (e.g.,

multiple persons in a vehicle, 2-man field tasks, field offices/trailers, etc.) the use of certain PPE, especially nose/mouth facial coverings as emission barriers, can serve as an alternative – see Section 8 below for more information.

3. Maintain Personal Hygiene

- Regular hand-washing – conduct regular and thorough handwashing with soap and water throughout the day; where a water supply for hand washing is not readily available, set up a 'field handwashing station' were feasible/appropriate; label water container "for handwashing only."
- Hand sanitizer - where water for handwashing is not available, utilize hand sanitizer frequently, then wash hands with soap and water as soon as possible.
- Facial tissues - carry a supply of facial tissues and use as much as possible for coughs/sneezes and dispose of used tissue in regular trash; "covering your cough" is acceptable, but use and disposal of tissues is more sanitary and therefore preferred.
- "Cover your cough" – when facial tissue is not ready at hand, cover your cough or sneeze by coughing/sneezing into the crook of your elbow--not into your hands; if you need to cough/sneeze into your hands, wash hands immediately.
- Personal hygiene supplies – in Geosyntec-controlled site trailers and other regularly-visited worksites, personal hygiene supplies including hand sanitizer, wipes, soap, and paper goods shall be maintained in adequate supply, as available for purchase.
- Minimize hand-contact with work surfaces and your face – develop changes in your typical work practices and personal habits to eliminate or minimize the frequency of hand contact with surfaces in your work environment (e.g., avoid unnecessary contact with work surfaces, open doors with minimal hand/finger contact, grip handrails with fingers or at intermittent junctures rather than sliding your hand the full length; etc.); limit habitual hand contact with your face; contact your face only after thorough hand washing; if it's necessary to contact your face, use the back of your hand or knuckles rather than your palm or finger tips.

4. Work Area Cleaning & Sanitation

- On-site trailers and similar indoor workspaces – increase the frequency of custodial services in on-site trailers/facilities at Geosyntec-controlled sites; disinfect "high-touch" surfaces regularly during each workday; cleaning and sanitation supplies shall be maintained in adequate supply and used regularly to clean/sanitize work surfaces.
- Clean "high-touch" work surfaces – wipe work surfaces with sanitizing cleaners, detergents or soap & water per the following – at the start and end of each work shift plus at periodic intervals of no more than 2 hours during the work period. High-touch items include cell phones, desktops, computer keyboards, tools, field equipment, coolers, doorknobs, refrigerators, microwaves, light switches, thermostats, faucet/toilet handles, latches on portable bathrooms, and similar items. Items being used/shared by more than 1 person should be cleaned before transferring.
- Cleaners/sanitizers - cleaning/disinfecting supplies may include commercial cleaners, detergents, disinfectants, or job-made solution[1] applied with commercial wipes or paper towels. See COVID cleaning and disinfection guidelines for more detail and full disinfection steps. Discard all used wipes/paper towels in regular trash.

[1] Per the CDC, a solution can be prepared by mixing: 5 tablespoons (1/3rd cup) bleach per gallon of water, or for smaller amounts 4 teaspoons bleach per quart of water.

- Housekeeping – appropriate housekeeping shall be maintained in all work areas; minimize/eliminate clutter and accumulations of trash and debris, particularly trash items that have received human contact (food wrappers, disposable cups, paper towels/tissues, etc.); minimizing clutter will facilitate regular cleaning of high-touch surfaces.

5. Minimize Travel-Related Risks

- Vehicle travel – regularly clean/disinfect high-touch surfaces (steering wheel, shift lever, door handles, tailgate, etc.) in personal vehicles, company field vehicles and rental vehicles; try to travel one person per vehicle, but no more than two; if traveling with others in the same vehicle, exercise physical distancing as possible within the vehicle and wear face masks/covers.
- Minimize stops - make as few stops as possible during travels to limit exposure to public spaces; and adhere to Journey Management Plan requirements (where applicable).
- Fuel/food/supply stops - when traveling by vehicle, and when stopping for fuel or other supplies is necessary, either clean/sanitize your hands upon completion of food/fuel stop, or wear gloves during the stop, then discard gloves and wash hands; utilize physical distancing (6 ft/2 m) during the stop; wear face mask/cover.
- Minimize/eliminate cash transactions – to minimize interpersonal contact, and to maintain appropriate physical distancing, use credit-card transactions where possible. Avoid passing credit cards to vendors is possible (prefer swipe/chip reader situations); of you must pass the credit card to someone clean up upon receiving it back.
- Air travel - to the extent possible, minimize/curtail air travel; Branch Manager approval is required for air travel; adhere to existing restrictions on domestic and international travel; have disinfectant wipes with you and wipe high-touch surfaces (head rest, tray, arm rest, lavatory latch); wear protective gloves and a face mask or cover, as available.
- Public transportation – avoid travel on trains, subways, buses, and other public transportation (i.e., ride share) where possible, especially in high-risk areas; if such travel is necessary, practice physical distancing, disinfect high-touch surfaces (seat, headrest, arm rest, hand-hold, etc.); wash hands thoroughly upon completion of travel; wear protective gloves and a face mask or cover, as available.
- Safe accommodations - book accommodations only at reputable hotel chains and verify with the hotel that appropriate protocols are in place to limit the potential exposure and spread of the virus by thorough cleaning and disinfection. Although such establishments are likely to be taking significant precautions against contact transfer between guests it is still preferable to avoid public areas/common spaces to the greatest degree possible.
- Critically assess with clients the need for travel and the potential for alternatives to face-to-face meetings and travel away from home, such as schedule changes and virtual meetings.

6. Utilize Safe Practices for Food & Beverage Provisions

- "BYOFB" - bring your own food and beverages with you to all work sites to avoid stopping at a store or restaurant; when shopping for food, obtain food for several days in advance to minimize the number of trips to the grocery store.
- Personal cooler – use your own personal lunch pack or cooler with ice packs refrozen daily for safe food storage during each workday; avoid use of "community" refrigerators.

- Physical distancing during meals - food should be eaten alone or at a minimum physical distance of approximately 2 m/6 ft between persons; dine in your vehicle or outside alone; avoid using the project trailer or common spaces in site facilities.

7. Avoid High-Risk Work Locations, 'Stop Work' Authority

- High-risk work – where work requires entry into high risk locations, including occupied residences or active/occupied health care facilities, correctional facilities, crowded public transportation areas, etc., specific additional protective measures may be required. All such work should be identified to H&S and coordination made to identify these measures prior to initiating the activity.
- Hazard elimination – all Geosyntec employees shall consider strategies for eliminating/mitigating the hazards associated with high-risk work; these strategies may include postponing the work, altering the scope of work to avoid the high hazard, modifying the schedule of work (for example to be conducted after sanitizing a work area), and related actions that eliminate elevated exposure risks.
- Stop-work authority - inform staff and coworkers that they have the authority to stop work if they suspect an unacceptable risk to the health or safety of participants; all employees are encouraged and expected to report elevated hazards to their supervisor/project manager; the H&S Department will assist in evaluating the risk and recommending safe work practices.

8. The Role of Personal Protective Equipment (PPE), When/Where Available

- PPE use is contingent upon availability - the use of disposable PPE, particularly disposable gloves and face masks or covers, may be employed to reduce the risk of exposure to and spread of COVID-19, particularly during unavoidable work tasks that may represent a high risk of exposure, and where alternate means of protection are less preferred; curtail work tasks considered high risk if appropriate PPE is not available.
- Face masks/covers used as emission barriers – the use of a nose/mouth facial covering offers a means for capturing potentially infectious droplets/aerosols produced by the wearer (i.e., from coughs, sneezes, speaking, etc.) and so mitigating the airborne release. This reduces the risk of others subsequently becoming exposed/infected by reducing airborne droplets/aerosols available to be inhaled or to settle onto surfaces. Therefore the wear of acceptable nose/mouth facial coverings[2] is authorized for unrestricted use by Geosyntec personnel for cases where the coverings are strictly used *as an emission barrier only* for COVID-19 exposure risk reduction, particularly where preferred physical distancing measures are impractical (e.g., 2-person tasks, multiple vehicle occupants, etc.) – see Section 2. This authorization does not include any use of these devices for the inhalation protection of the wearer; such cases (e.g., work in high risk areas as discussed in Section 7) must always be approved by H&S (see next bullet).
- Use of respirators and other face masks for wearer inhalation protection - in situations where workers require inhalation protection from an airborne COVID-19 hazard (e.g., entry into a high-

[2] Acceptable nose/mouth facial coverings for use as emission barriers (only) include: Loose-fitting masks (commonly termed "surgical masks"), tight-fitting masks where the device body is the filtering material and the design does NOT incorporate an exhalation valve of any kind (irrespective of protection rating, such as N95, P99, KN95, etc.), or even home-made or make-shift face covers (e.g., home-made masks, bandanas, balaclavas, etc.). Note: Any negative pressure elastomeric respirator devices utilizing filter cartridges (e.g., ½-face or full-face respirators) are strictly prohibited from use as emission barriers - use of such devices is for wearer inhalation protection only and requires prior concurrence from the H&S manager.

risk location such as a hospital – see Section 7), plans MUST be coordinated directly with your H&S manager to ensure that a proper risk assessment and device selection is conducted and that all elements of a respiratory protection program are implemented. *No use of <u>any</u> type of respiratory protection device that is intended to control the wearer's inhalation exposure is authorized without the express consent of the H&S manager*.

- <u>Disposable gloves</u> – where contact with potentially contaminated surfaces may occur the prevention of "hand-to-face" transfer of material is important to mitigate exposure risk, and requires frequent hand washing and disinfection. Surgical-type gloves made of nitrile or vinyl[3] provide a means of simplifying this decontamination and is especially preferable in high-risk circumstances where proper washing/disinfection could become excessive or where access to cleaning stations is not readily available. Gloves must be removed and disposed of after a specific task, and upon removal wearers must wash hands (for a minimum of 20 seconds) or apply hand sanitizer (>60% alcohol) immediately.

9. <u>Maintain Healthy Lifestyle, Facilitate "Wellness"</u>

- <u>Personal wellness</u> – Spend extra effort to stay well (e.g., eat healthy, get enough rest) to maintain a strong immune system; develop strategies to maintain emotional wellness.
- <u>Exercise, stretching</u> – make time for solitary physical exercise, stretching, yoga or similar activities; avoid group activities where possible; maintain physical distancing; use only your own personal exercise equipment and accessories.
- <u>Ergonomics</u> – as employees are adjusting to new work strategies, which may entail working from home in a non-office environment, all employees are encouraged to consider strategies for maintaining appropriate work-station ergonomics.

10. <u>Information, Communication, Coordination</u>

- <u>Information updates</u> – employees are encouraged to stay up to date with the latest information and updates to Company operating procedures regarding COVID-19; include this information at all safety meetings and incorporate related safe work practices into written safety plans (HASPs/THAs).
- <u>Client requirements</u> - for job sites under the control of another organization, obtain a copy of any relevant COVID-19 exposure control requirements and ensure we can fully comply; H&S can assist in evaluating such plans as needed. Understand contract requirements for Geosyntec to staff projects, anticipate disruptions of our ability to serve the project that are out of our control, and develop contingency plans for such situations.
- <u>Plan, communicate, coordinate</u> – prior to the start of fieldwork on each project, conduct a pre-work safety orientation with each member of the project/field team (as well as with clients, subcontractors, other contractors, as applicable) to determine the scope of prevention measures for COVID-19 and other site hazards; delineate key elements in the written safety plan; communicate/coordinate safety measures daily throughout the performance of field activities.
- <u>Government rules/restrictions</u> – all project teams shall adhere to government mandates and restrictions relevant in the jurisdiction of your fieldwork; information on such requirements may be obtained from Geosyntec personnel familiar with your work location, or through client contacts.

[3] Latex gloves are also effective and acceptable for protection against COVID-19 but come with a low risk of severe latex allergy to allergic individuals.

- Work task innovations – all employees are encouraged to consider innovative ways of conducting their work to reduce the risks of contracting or transmitting COVID-19; learn new communication capabilities through available technologies (WebEx, Skype, MS Teams, Office 365) and develop safety innovations for on-site field work; modify your work tasks and use non-typical field practices to maintain physical distancing, personal hygiene, and work area sanitation.

Here are some additional resources to provide to employees and post in field office locations

- COVID-19 Factsheet
- Keep Calm and Wash Your Hands
- Wash Your Hands!
- Make a Field Hand Washing Station
- Making Hand Washing Solution from Liquid Bleach
- Know the facts about Coronavirus Disease 2019 and help stop the spread of rumors

ATTACHMENT A
Previous Perchlorate Analytical Results

TABLE 2-1
Groundwater Perchlorate Results Summary - 2004 Through 2011
Perchlorate Remedial Investigation
Shieldalloy Metallurgical Corporation
Newfield, New Jersey

WELL IDENTIFIER	SCREENED INTERVAL (FTBGS)[1]	RELATIVE AQUIFER DEPTH	PERCHLORATE (µg/L) SAMPLING EVENT							
			JULY 27, 2004	SEPTEMBER 10, 2004	SEPTEMBER 30, 2004	OCTOBER 27, 2004	FEBRUARY 21, 2006	OCTOBER 20-22, 2009[2]	SEPTEMBER 8-9, 2010	APRIL 29, 2011
ON-SITE MONITORING WELLS										
IWC-1	15-20	Shallow	**9.9**	**10.0**	NA	NA	NA	**7.3**	NA	NA
IWC-2	35-40	Shallow	**10**	**9.4**	NA	NA	NA	**7.7**	NA	NA
IWC-3	55-60	Intermediate	4.0 / 4.1	4.0 / 4.0	NA	NA	NA	2.5 J [3]	NA	NA
IWC-4	75-80	Intermediate	**5.4**	**6.9**	NA	NA	NA	4.6	4.4	NA
IWC-5	95-100	Deep	**10.0**	**11.0**	NA	NA	NA	**11.7 / 10.7**[4]	NA	NA
A	114-124	Deep	NA	<0.18	NA	NA	NA	<3.0	NA	NA
B	36-46	Shallow	NA	**8.0**	NA	NA	NA	1.2 J [3]	NA	NA
K	36-46	Shallow	NA	NA	NA	NA	NA	**90.5 / 78.1**	1.9 J[6] / 3.0	NA
L	42-52	Shallow	NA	NA	NA	NA	NA	<3.0	NA	NA
SC9S	15-30	Shallow	NA	**8.0**	NA	NA	NA	**8.2 / 8.0**[5]	NA	NA
SC11S(R)	9-24	Shallow	NA	NA	NA	NA	NA	<3.0	<3.0	NA
SC12S	15-25	Shallow	NA	NA	NA	NA	NA	<3.0	NA	NA
SC12D	126-136	Deep	NA	NA	NA	NA	NA	<3.0	<3.0	NA
SC13S(R)	14.7-24.7	Shallow	NA	NA	NA	NA	NA	<3.0	NA	NA
SC13D	127-137	Deep	NA	NA	NA	NA	NA	2.2 J [6]	NA	NA
SC14S	12-27	Shallow	NA	0.21 J	NA	NA	NA	<3.0	<3.0	NA
SC15S	12.5-27.5	Shallow	NA	NA	NA	NA	NA	<3.0	NA	NA
SC16S	12-27	Shallow	NA	NA	NA	NA	NA	<3.0	<3.0	NA
SC20S	7-22	Shallow	NA	NA	NA	NA	NA	<3.0	NA	NA
SC20D	129-139	Deep	NA	NA	NA	NA	NA	**7.0**	**6.0**	NA
SC22S	3-18	Shallow	NA	NA	NA	NA	NA	<3.0	2.0 J[6]	NA
SC23S	9-24	Shallow	NA	NA	NA	NA	NA	<3.0	NA	NA
SC25S	7-22	Shallow	NA	NA	NA	NA	NA	<3.0	0.64 J[6]	NA
SC27S	7-22	Shallow	NA	NA	NA	NA	NA	<3.0	NA	NA
MWH-4	119-129	Deep	NA	NA	NA	NA	NA	<3.0	NA	NA
W2(R)	2-17	Shallow	NA	NA	NA	NA	NA	0.94 J [6]	<3.0	NA
W3D	88-108	Deep	NA	NA	NA	NA	NA	**8.6**	**7.4**	NA
W4	55-75	Intermediate	NA	NA	NA	NA	NA	1.2 J[6]	0.93 J[6]	NA

NOTES:

(1) - FTBGS, Feet Below Ground Surface
(2) - Monitoring wells SC33D & SC34D were sampled on 11/19/09, monitoring wells SC35D & SC36D were sampled on 12/7/09, monitoring well K was re-sampled on 1/21/10, & recovery wells Layne & W9 were sampled on 1/21/10
(3) - Data qualifier changed to "J" by data validation
(4) - "Blind" duplicate sample labeled as IWC-6
(5) - "Blind" duplicate sample labeled as SC33S
(6) - Data not validated, but qualifier changed to "J" consistent with data validation
(7) - Data validation corrected reporting limit
(8) - "Blind" duplicate sample labeled as SC35D
(9) - "Blind" duplicate sample labeled as SC37D
(10) - "Blind" duplicate sample labeled as SC34D

µg/L - micrograms per liter
NA - Not Analyzed
All samples were analyzed by EPA Method 314.0
BOLD - indicates that value is greater than the perchlorate action level of 5 µg/L (2006 ACO)
Shaded - Indicates that value is greater than the EPA Interim Health Advisory Level of 15 µg/L
J - Indicates a result is less than the reporting limit and estimated by the laboratory
Results with slash (e.g., 13.0 / 12.9) indicate duplicate results

TABLE 2-1
Groundwater Perchlorate Results Summary - 2004 Through 2011
Perchlorate Remedial Investigation
Shieldalloy Metallurgical Corporation
Newfield, New Jersey

WELL IDENTIFIER	SCREENED INTERVAL (FTBGS)[1]	RELATIVE AQUIFER DEPTH	PERCHLORATE (µg/L) SAMPLING EVENT							
			JULY 27, 2004	SEPTEMBER 10, 2004	SEPTEMBER 30, 2004	OCTOBER 27, 2004	FEBRUARY 21, 2006	OCTOBER 20-22, 2009[2]	SEPTEMBER 8-9, 2010	APRIL 29, 2011
OFF-SITE MONITORING WELLS										
OBS-2A	129-149	Deep	NA	NA	NA	NA	NA	4.8 J [6]	NA	NA
IW1	32-62	Intermediate	NA	NA	NA	NA	NA	1.1 J [6]	NA	NA
SC4S	35-45	Shallow	NA	NA	1.1	NA	NA	<3.0	NA	NA
SC6S	45-75	Intermediate	NA	NA	1.6	NA	NA	**6.4**	**19.6**	NA
SC6D	110-120	Deep	NA	NA	3.5	NA	NA	**9.8**	NA	NA
SC10S	35-55	Shallow	NA	NA	NA	NA	NA	1.7 J [6]	<3.0	NA
SC10D	105-125	Deep	NA	NA	NA	NA	NA	**19.5**	**8.5**	NA
SC17S	19-28	Shallow	NA	NA	NA	NA	NA	<3.0	<3.0	NA
SC17D	143-153	Deep	NA	NA	NA	NA	NA	**6.3**	**5.6**	NA
SC18S	4-19	Shallow	NA	NA	NA	NA	NA	<15.0 [7]	<3.0	NA
SC18D	119-129	Deep	NA	NA	NA	NA	NA	3.8	NA	NA
SC19S	2-17	Shallow	NA	NA	NA	NA	NA	<3.0	NA	NA
SC19D	120-130	Deep	NA	NA	NA	NA	NA	**14.3**	NA	NA
SC21S	3-18	Shallow	NA	NA	NA	NA	NA	<3.0	<3.0	NA
SC21D	125-135	Deep	NA	NA	NA	NA	NA	**29.1**	**32.8**	NA
SC26D	127-137	Deep	NA	NA	NA	NA	NA	**11.0**	**6.8**	NA
SC28D	133-153	Deep	NA	NA	NA	**34.0**	NA	**49.0**	**16.8**	NA
SC30D	147-157	Deep	NA	NA	NA	1.9	NA	2.6 J [6]	2.8 J[6]	NA
SC32D	92-102	Deep	NA	NA	NA	NA	NA	3.2 / 3.3[8]	3.7	NA
SC33D	82.5-92.5	Intermediate	NA	NA	NA	NA	NA	<3.0	<3.0	NA
SC34D	130-140	Deep	NA	NA	NA	NA	NA	**150 / 152[9]**	**158**	NA
SC35D	89.5-99.5	Deep	NA	NA	NA	NA	NA	2.0 J [6]	2.7 J[6]	NA
SC36D	107-117	Deep	NA	NA	NA	NA	NA	**5.3**	**6.4 / 5.6[9]**	NA
SC40D	120-130	Deep	NA	NA	NA	NA	NA	NA	NA	4.0 / 3.9 [11]
ON-SITE EXTRACTION WELLS										
Layne	42-47	Shallow	NA	**23.0**	NA	NA	NA	**67.4**	**36.6**	NA
W9	110-130	Deep	NA	**10.0**	NA	NA	NA	**6.1**	NA	NA

NOTES:

(1) - FTBGS, Feet Below Ground Surface
(2) - Monitoring wells SC33D & SC34D were sampled on 11/19/09, monitoring wells SC35D & SC36D were sampled on 12/7/09, monitoring well K was re-sampled on 1/21/10, & recovery wells Layne & W9 were sampled on 1/21/10
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(7) - Data validation corrected reporting limit
(8) - "Blind" duplicate sample labeled as SC35D
(9) - "Blind" duplicate sample labeled as SC37D
(10) - "Blind" duplicate sample labeled as SC34D
(11) - "Blind" duplicate sample labeled as SC49D

µg/L - micrograms per liter
NA - Not Analyzed
All samples were analyzed by EPA Method 314.0
BOLD - indicates that value is greater than the perchlorate action level of 5 µg/L (2006 ACO)
Shaded - Indicates that value is greater than the EPA Interim Health Advisory Level of 15 µg/L
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Perchlorate Remedial Investigation
Shieldalloy Metallurgical Corporation
Newfield, New Jersey

WELL IDENTIFIER	SCREENED INTERVAL (FTBGS)[1]	RELATIVE AQUIFER DEPTH	PERCHLORATE (µg/L) SAMPLING EVENT							
			JULY 27, 2004	SEPTEMBER 10, 2004	SEPTEMBER 30, 2004	OCTOBER 27, 2004	FEBRUARY 21, 2006	OCTOBER 20-22, 2009[2]	SEPTEMBER 8-9, 2010	APRIL 29, 2011
FARM PARCEL MONITORING WELLS										
IW2	40-70	Intermediate	NA	NA	NA	NA	NA	3.7	NA	NA
SC1S	35-55	Intermediate	NA	NA	NA	3.5	**8.8**	1.8 J [3]	0.69 J[3]	NA
SC1D	85-95/100-115	Deep	NA	NA	NA	**76.0 / 76.0**	**53.9**	**46.3**	**44.5**	NA
SD2D(R)	106-116	Deep	NA	NA	**9.2**	NA	NA	**7.0**	**6.6**	NA
SC3S	35-55	Intermediate	NA	NA	**13**	NA	**20.9**	1.8 J [3]	**13.0**	NA
SC3D(R)	102-112	Deep	NA	NA	**49**	NA	**62.1**	**141 / 136[10]**	**143**	NA
SC5S	5-20	Shallow	NA	NA	NA	NA	NA	1.4 J [6]	NA	NA
SC5D	90-120	Deep	NA	NA	NA	NA	NA	1.2 J [6]	NA	NA
SC24S	5-20	Shallow	NA	NA	NA	4.8	4.3	0.99 J [6]	2.1 J[3]	NA
SC24D	105-115	Deep	NA	NA	NA	**6**	3.0	3.0	NA	NA
SC31D	120-130	Deep	NA	NA	NA	NA	NA	**6.6**	NA	NA
OFFSITE EXTRACTION WELLS										
RIW2	30-55	Shallow	NA	NA	**14.0 / 15.1**	NA	**9.4**	4.1	NA	NA
RW6S	55-75	Intermediate	NA	NA	**8.0 / 8.01**	NA	NA	**12.9**	NA	NA
RW6D	90-125	Deep	NA	NA	**12.0 / 13.8**	NA	NA	**14.3**	NA	NA

NOTES:

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(8) - "Blind" duplicate sample labeled as SC35D
(9) - "Blind" duplicate sample labeled as SC37D
(10) - "Blind" duplicate sample labeled as SC34D

µg/L - micrograms per liter
NA - Not Analyzed / Not Applicable
All samples were analyzed by EPA Method 314.0
BOLD - indicates that value is greater than the perchlorate action level of 5 µg/L (2006 ACO)
Shaded - Indicates that value is greater than the EPA Interim Health Advisory Level of 15 µg/L
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Results with slash (e.g., 13.0 / 12.9) indicate duplicate results

TABLE 2-2
Current and Previous Off-Site Groundwater Vertical Profiling Perchlorate Results
Perchlorate Remedial Investigation
Shieldalloy Metallurgical Corporation
Newfield, New Jersey

Sample ID	Date Sampled	Approx. Ground Surface Elevation (ftmsl)	Sample Depth (ftbgs)	Approx. Sample Elevation (ftmsl)	Relative Aquifer Depth	Perchlorate (ug/L)
Vertical Profile Samples (2009 Investigation)						
VP-13 (25-30)	10/14/2009	102	25-30	77 to 72	Shallow	<3.0
VP-13 (50-55)	10/14/2009	102	50-55	52 to 47	Shallow	<3.0
VP-13 (75-80)	10/14/2009	102	75-80	27 to 22	Intermediate	3.9
VP-13 (100-105)	10/15/2009	102	100-105	2 to -3	Deep	**10.6**
VP-13 (125-130)	10/15/2009	102	125-130	-23 to -28	Deep	**5.7**
VP-13A (15-20)	10/22/2009	89	15-20	74 to 69	Shallow	<3.0
VP-13A (37-42)	10/22/2009	89	37-42	52 to 47	Shallow	<3.0
VP-13A (62-67)	10/22/2009	89	62-67	27 to 22	Intermediate	4.3
VP-13A (87-92)	10/23/2009	89	87-92	2 to -3	Deep	3.4
VP-13A (111-116)	10/23/2009	89	111-116	-22 to -27	Deep	**6.0**
VP-14 (35-40)	10/16/2009	100	35-40	65 to 60	Shallow	0.93 J (2)
VP-14 (55-60)	10/16/2009	100	55-60	45 to 40	Shallow	<3.0
VP-14 (80-85)	10/19/2009	100	80-85	20 to 15	Intermediate	1.6 J (1)
VP-14 (105-110)	10/19/2009	100	105-110	-5 to -10	Deep	**6.2**
VP-24 (105-110) Field Dup	10/19/2009	100	105-110	-5 to -10	Deep	**5.9**
VP-14 (130-135)	10/19/2009	100	130-135	-30 to -35	Deep	**12.5**
VP-15 (30-35)	10/12/2009	91	30-35	61 to 56	Shallow	<3.0
VP-15 (45-50)	10/12/2009	91	45-50	46 to 41	Shallow	<3.0
VP-15 (65-70)	10/13/2009	91	65-70	26 to 21	Intermediate	<3.0
VP-15 (88-93)	10/13/2009	91	88-93	3 to -2	Deep	4.9
VP-15 (114-119)	10/13/2009	91	114-119	-23 to -28	Deep	<3.0
VP-15A (15-20)	10/20/2009	76	15-20	61 to 56	Shallow	<3.0
VP-15A (38-43)	10/21/2009	76	38-43	38 to 33	Shallow	<3.0
VP-15A (55-60)	10/21/2009	76	55-60	21 to 16	Intermediate	<3.0
VP-15A (77-82)	10/21/2009	76	77-82	-1 to -6	Deep	1.6 J (2)
VP-15A (99-104)	10/21/2009	76	99-104	-23 to -28	Deep	2.5 J (2)
VP-25A (99-104) Field Dup	10/21/2009	76	99-104	-23 to -28	Deep	2.9 J (2)

NOTES:

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BOLD - indicates that value is greater that the perchlorate action level of 5 µg/L

Shaded - Indicates that value is greater than the EPA Interim Health Advisory Level of 15 µg/L

micrograms per Liter (µg/L) is equivalent to parts per billion

ftmsl - feet above mean sea level (NAVD 27)

ftbgs - feet below ground surface

J - Indicates a result is less than the reporting limit and estimated by the laboratory

TABLE 2-2
Current and Previous Off-Site Groundwater Vertical Profiling Perchlorate Results
Perchlorate Remedial Investigation
Shieldalloy Metallurgical Corporation
Newfield, New Jersey

Sample ID	Date Sampled	Approx. Ground Surface Elevation (ftmsl)	Sample Depth (ftbgs)	Approx. Sample Elevation (ftmsl)	Relative Aquifer Depth	Perchlorate (ug/L)
Vertical Profile Samples (2006/2007 Investigation)						
VP-1 (15-20)	11/28/2006	85	15-20	70 to 65	Shallow	<0.3
VP-1 (35-40)	11/28/2006	85	35-40	50 to 45	Shallow	<0.3
VP-1 (60-65)	11/29/2006	85	60-65	25 to 20	Intermediate	<0.3
VP-1 (85-90)	11/29/2006	85	85-90	0 to -5	Deep	**5.6**
VP-1 (105-110)	11/29/2006	85	105-110	-20 to -25	Deep	3.0
VP-2 (15-20)	11/30/2006	85	15-20	70 to 65	Shallow	<0.3
VP-2 (35-40)	12/1/2006	85	35-40	50 to 45	Shallow	4.2
VP-2 (60-65)	12/1/2006	85	60-65	25 to 20	Intermediate	**9.6**
VP-2 (85-90)	12/1/2006	85	85-90	0 to -5	Deep	**49.9**
VP-2 (110-115)	12/1/2006	85	110-115	-25 to -30	Deep	**9.4**
VP-3 (25-30)	12/4/2006	95	25-30	70 to 65	Shallow	<0.3
VP-3 (45-50)	12/5/2006	95	45-50	50 to 45	Shallow	<0.3
VP-30 (45-50) Field Dup	12/5/2006	95	45-50	50 to 45	Shallow	<0.3
VP-3 (70-75)	12/6/2006	95	70-75	25 to 20	Intermediate	**7.9**
VP-3 (95-100)	12/6/2006	95	95-100	0 to -5	Deep	**34**
VP-3 (115-120)	12/6/2006	95	115-120	-20 to -25	Deep	**28.3**
VP-4 (30-35)	12/11/2006	100	30-35	70 to 65	Shallow	1.3
VP-4 (50-55)	12/11/2006	100	50-55	50 to 45	Intermediate	1.3
VP-4 (75-80)	12/11/2006	100	75-80	25 to 20	Intermediate	3.3
VP-4 (75-80) Field Dup	12/11/2006	100	75-80	25 to 20	Intermediate	3.1
VP-4 (100-105)	12/11/2006	100	100-105	0 to -5	Deep	<0.3
VP-4 (121-126)	12/11/2006	100	121-126	-21 to -26	Deep	**6.8**
VP-10 (20-25)	12/15/2006	85	20-25	65 to 60	Shallow	2.4
VP-10 (35-40)	12/15/2006	85	35-40	50 to 45	Shallow	<0.3
VP-10 (60-65)	12/18/2006	85	60-65	25 to 20	Intermediate	3.4
VP-100 (60-65) Field Dup	12/18/2006	85	60-65	25 to 20	Intermediate	3.4
VP-10 (85-90)	12/18/2006	85	85-90	0 to -5	Deep	**17.4**
VP-10 (109-114)	12/18/2006	85	109-114	-24 to -29	Deep	**6.7**

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Shaded - Indicates that value is greater than the EPA Interim Health Advisory Level of 15 µg/L

micrograms per Liter (µg/L) is equivalent to parts per billion

ftmsl - feet above mean sea level (NAVD 27)

ftbgs - feet below ground surface

TABLE 2-3
Soil Investigation Perchlorate Results
Perchlorate Remedial Investigation
Shieldalloy Metallurgical Corporation
Newfield, New Jersey

Sample ID	Date Sampled	Sample Depth (ftbgs)	Perchlorate (ug/kg)
Background Sample			
SS-01 (0-1')	8/30/2012	0-1	<1.2
SS-01 (5-7')	10/26/2009	5-7	<9.6
SS-01 (12-14')	10/26/2009	12-14	<10
AOC-1 Former Chemical Storage Building			
SS-02 (1-3')	10/26/2009	1-3	2.1 J(1)
SS-02 (14-16')	10/26/2009	14-16	<9.7
SS-03 (0-2')	10/26/2009	0-2	<10
SS-03 (13-15')	10/26/2009	13-15	8.6 J(1)
SS-04 (0-1')	8/30/2012	0-1	<1.2
SS-04 (2-4')	10/26/2009	2-4	7.9 J(1)
SS-04 (14-16')	10/26/2009	14-16	4.2 J(1)
SS-05 (0-1')	8/30/2012	0-1	<1.2
SS-05 (5-7')	10/26/2009	5-7	58.3
SS-05 (13-15')	10/26/2009	13-15	18.3
SS-06 (1-3')	10/26/2009	1-3	<10
SS-06 (14-16')	10/26/2009	14-16	2.9 J(1)
SS-07 (6-8')	10/26/2009	6-8	<9.6
SS-27 (6-8') Field Dup	10/26/2009	6-8	<9.6
SS-07 (13-15')	10/26/2009	13-15	3.0 J(1)
SS-08 (3-4')	10/26/2009	3-4	<9.9
SS-08 (12-14')	10/26/2009	12-14	<9.6
AOC-2 Former Building D102(A)			
SS-21 (0-1')	8/30/2012	0-1	5.9 J(1)
SS-21 (1-3')	10/28/2009	1-3	11.0
SS-21 (5-7')	10/28/2009	5-7	10.7
SS-22 (1-3')	10/28/2009	1-3	<9.8
SS-22 (6-8')	10/28/2009	6-8	12.0
SS-23 (2-4')	10/28/2009	2-4	<10
SS-33 (2-4') Field Dup	10/28/2009	2-4	<10
SS-23 (6-8')	10/28/2009	6-8	<9.7
SS-24 (0-1')	8/30/2012	0-1	<1.2
SS-24 (1-3')	10/28/2009	1-3	26.5
SS-24 (4-6')	10/28/2009	4-6	28.8

Sample ID	Date Sampled	Sample Depth (ftbgs)	Perchlorate (ug/kg)
AOC-3 Former Lagoon Area			
SS-09 (0-1')	8/30/2012	0-1	<1.2
SS-09 (6-8')	10/26/2009	6-8	<10
SS-09 (12-14')	10/26/2009	12-14	<10
SS-10 (2-4')	10/26/2009	2-4	<9.8
SS-10 (4-6')	10/26/2009	4-6	<9.4
SS-11 (1-3')	10/27/2009	1-3	<9.8
SS-11 (5-7')	10/27/2009	5-7	2.8 J(2)
SS-12 (2-4')	10/27/2009	2-4	<9.7
SS-12 (5-7')	10/27/2009	5-7	<9.6
SS-32 (5-7') Field Dup	10/27/2009	5-7	<9.6
SS-13 (0-1')	8/30/2012	0-1	<1.2
SS-13 (1-3')	10/27/2009	1-3	2.0 J(2)
SS-13 (5-7')	10/27/2009	5-7	2.9 J(2)
SS-14 (1-3')	10/27/2009	1-3	<9.5
SS-14 (6-8')	10/27/2009	6-8	<9.6
SS-15 (0-1')	8/30/2012	0-1	<1.2
SS-15 (2-4')	10/27/2009	2-4	<9.7
SS-15 (4-6')	10/27/2009	4-6	<9.9
SS-16 (1-3')	10/27/2009	1-3	<9.6
SS-16 (6-8')	10/27/2009	6-8	<9.9
SS-17 (1-3')	10/27/2009	1-3	<9.7
SS-17 (5-7')	10/27/2009	5-7	2.8 J(2)
SS-18 (1-3')	10/27/2009	1-3	<10
SS-18 (6-8')	10/27/2009	6-8	<9.3
SS-19 (1-3')	10/27/2009	1-3	<9.8
SS-19 (6-8')	10/27/2009	6-8	<9.6
SS-20 (0-1')	8/30/2012	0-1	<1.2
SS-20 (1-3')	10/27/2009	1-3	2.3 J(2)
SS-20 (4-6')	10/27/2009	4-6	<10

NOTES:

(1) - Data qualifier changed to "J" by data validation

(2) - Data not validated, but qualifier changed to "J" consistent with data validation

EPA Regional Screening Level for perchlorate in residential soil is 55,000 µg/kg and 720,000 µg/kg in industrial soil.

Shaded results are in excess of the EPA Regional Screening Level for perchlorate.

micrograms per Liter (µg/kg) is equivalent to parts per billion

ftbgs - feet below ground surface

J - Indicates a result is less than the reporting limit and estimated by the laboratory

TABLE 2-4
Soil Investigation, Monitoring/Extraction Well Sampling, Groundwater Vertical Profiling, and Surface Water and Sediment QA/QC Results
Perchlorate Remedial Investigation
Shieldalloy Metallurgical Corporation
Newfield, New Jersey

Sample ID	Date Sampled	Perchlorate (µg/L)
Soil / Sediment Investigation Field Blank Samples		
FB102609(1)	10/26/2009	<3.0
FB102609(2)	10/26/2009	<3.0
FB102709(1)	10/27/2009	<3.0
FB102709(2)	10/27/2009	<3.0
FB102809(for SS Samples)	10/28/2009	<3.0
FB102809(for SED Samples)	10/28/2009	<3.0
Monitoring/Extraction Well Sampling Field Blank Samples		
FB102009A	10/20/2009	<3.0
FB102109	10/21/2009	<3.0
FB102209	10/22/2009	<3.0
FB111909	11/19/2009	<3.0
FB090810	9/8/2010	<3.0
FB090910	9/9/2010	<3.0
FB042911	4/29/2011	<3.0
Groundwater Vertical Profiling Field Blank Samples		
FB101209	10/12/2009	<3.0
FB101309	10/13/2009	<3.0
FB101409	10/14/2009	<3.0
FB101509	10/15/2009	<3.0
FB101609	10/16/2009	<3.0
FB101909	10/19/2009	<3.0
FB102009	10/20/2009	<3.0
FB102109	10/21/2009	<3.0
FB102209	10/22/2009	<3.0
FB102309	10/23/2009	<3.0
Environmental Samples / "Blind" Duplicate Samples		
Monitoring Well Sampling		
IWC-5 / IWC-6	10/21/2009	11.7 / 10.7
SC9S / SC33S	10/21/2009	8.2 / 8.0
SC32D / SC35D	10/22/2009	3.2 / 3.3
SC3D(R) / SC34D	10/21/2009	141 / 136
SC34D / SC37D	11/19/2009	150 / 152
SC36D / SC37D	9/8/2010	6.4 / 5.6
SC40D / SC49D	4/29/2011	4.0 / 3.9
K / J	9/9/2010	1.9J / 3.0
Groundwater Vertical Profiling		
VP-14(105-110) / VP-24(105-110)	10/19/2009	6.2 / 5.9
VP-15A(99-104) / VP-25A(99-104)	10/21/2009	2.5J / 2.9J
Soil Investigation*		
SS-07(6-8') / SS-27(6-8')	10/26/2009	<9.6 / <9.6
SS-12(5-7') / SS-32(5-7')	10/27/2009	<9.6 / <9.6
SS-23(2-4') / SS-33(2-4')	10/28/2009	<10 / <10
Surface Water / Sediment Investigation		
SED-4 / SED-10*	10/28/2009	10.9J / <42
SW-4 / SW-10	10/28/2009	<3.0 / <3.0

NOTES:

Action Level for Perchlorate is 5 µg/L (per Administrative Consent Order signed February 1, 2006).

micrograms per Liter (µg/L) is equivalent to parts per billion

J - Indicates a result is less than the reporting limit and estimated by the laboratory

* - Soil and sediment perchlorate results are presented in micrograms per kilogram (µg/kg)

TABLE 2-5
Surface Water and Sediment Investigation Perchlorate Results
Perchlorate Remedial Investigation
Shieldalloy Metallurgical Corporation
Newfield, New Jersey

Sample ID	Date Sampled	Perchlorate	
		Surface Water (ug/l)	Sediment (ug/kg)
Surface Water / Sediment Sample Identifications			
SW-1A / SED-1A	10/28/2009	1.8 J (1)	<12
SW-1 / SED-1	10/28/2009	<3.0	<18
SW-2 / SED-2	10/28/2009	<3.0	<19 (2)
SW-3 / SED-3	10/28/2009	<3.0	<13
SW-4 / SED-4	10/28/2009	<3.0	10.9 J (1)
SW-10 / SED-10 Field Dup	10/28/2009	<3.0 (2)	<42
SW-5 / SED-5	10/28/2009	<3.0	<27
SW-6 / SED-6	10/28/2009	<3.0	<16
SW-7 / SED-7	10/29/2009	<3.0	<21
SED-8	10/29/2009	Dry	<11
SW-9 / SED-9	10/29/2009	<3.0	<47

NOTES:

(1) - Data qualifier changed to "J" by data validation

(2) - Data validation indicated analytical result should be reported as less than the laboratory reporting limit

There are no established guidance or criteria for perchlorate in surface water or sediment

micrograms per Liter (µg/L) is equivalent to parts per billion

ftmsl - feet above mean sea level (NAVD 27)

ftbgs - feet below ground surface

J - Indicates a result is less than the reporting limit and estimated by the laboratory

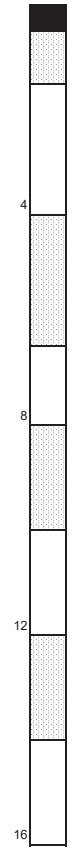
ATTACHMENT B

Relevant Boring Logs, Vertical Profiling Logs, and Well Construction Diagrams

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-01
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/26/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/26/09
Boring Location: Background	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	1.2	NA	0-0.3	TOPSOIL.
				0.3-1.2	Orange-brown F-M SAND, little c-gravel, trace silt, trace f-gravel.
				1.2-4	No Recovery.
4-8	4	2.6	NA	0-2.6	Orange-brown M-C SAND, trace silt.
				2.6-4	No Recovery.
8-12	4	1.8	NA	0-1.8	Orange-brown M-C SAND, trace silt, trace c-gravel.
				1.8-4	No Recovery.
12-16	4	2	NA	0-2	Orange-brown M-C SAND, some m-c gravel, trace silt. Wet at 14 fbg.
				2-4	No Recovery.

Lithology



Legend

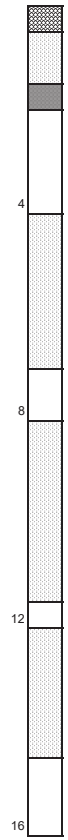
- Topsoil
- Sand
- No Recovery

Collect SS-01 (5-7)
Collect SS-01 (12-14)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-02
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/26/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/26/09
Boring Location: Near former storage shed	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	2	NA	0-0.6	Gray ASH and M-C GRAVEL.
				0.6-1.2	Brown F-M SAND with some silty clay.
				1.2-2	Orange-brown SILTY CLAY with some f-m sand.
				2-4	No Recovery.
4-8	4	3	NA	0-0.8	Orange-brown F-M SAND, some clay.
				0.8-3	Orange-brown F-M SAND, trace silt, trace f-m gravel.
				3-4	No Recovery.
8-12	4	3.3	NA	0-3.3	Orange-brown M-C SAND, trace f-m gravel.
				3.3-4	No Recovery.
12-16	4	2.7	NA	0-2.7	Orange-brown M-C SAND, trace f-gravel, trace silt. Wet at 15.5-16 fbg.
				2.7-4	No Recovery,

Lithology



Legend

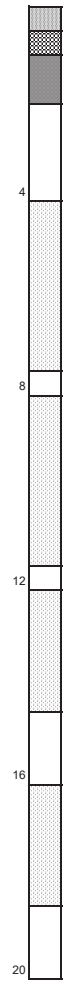
- Topsoil
- Sand
- Silty Clay
- Gravel
- No Recovery

Collect SS-02 (1-3)
Collect SS-02 (14-16)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-03
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/26/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/26/09
Boring Location: Near former storage shed	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	2	NA	0-0.4	Gray-brown F-M SAND and SILT, some m-c gravel.
				0.4-0.8	Light gray ASH with some m-c gravel, very moist.
				0.8-2	Orange-brown SILTY CLAY, some f-m sand, trace f-gravel.
				2-4	No Recovery.
4-8	4	3.6	NA	0-3.6	Orange-brown F-M SAND, little silt, little f-gravel.
				3.6-4	No Recovery.
8-12	4	3.3	NA	0-2.7	Orange-brown F-M SAND, little silt, little f-gravel.
				2.7-3.3	M-C SAND, trace silt, some m-c gravel.
				3.3-4	No Recovery.
12-16	4	2.5	NA	0-2.5	Orange-brown M-C SAND, trace silt, trace f-gravel, wet at 15.5-16 fbg.
				2.5-4	No Recovery.
16-20	4	2.5	NA	0-2.5	Orange-brown M-C SAND, little f-m gravel, wet.
				2.5-4	No Recovery.

Lithology



Legend

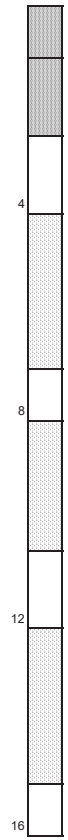
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-03 (0-2)
Collect SS-03 (13-15)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-04
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/26/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/26/09
Boring Location: Near former storage shed	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	2.6	NA	0-1	Brown VF-M SAND and SILT, little m-c gravel.
				1-2.6	Orange-brown F-M SAND and SILT, trace clay, little f-m gravel.
				2.6-4	No Recovery.
4-8	4	3	NA	0-3	Orange-brown F-M SAND, some silt, little f-m gravel.
				3-4	No Recovery.
8-12	4	2.7	NA	0-2.7	Orange-brown M-C SAND, trace silt, little f-m gravel.
				2.7-4	No Recovery.
12-16	4	2.9	NA	0-2.9	Orange-brown M-C SAND, trace silt, little f-m gravel, wet at 15-16 fbg.
				2.9-4	No Recovery.

Lithology



Legend

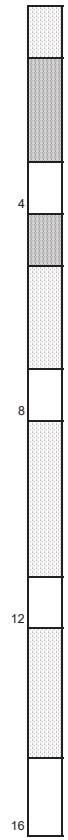
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-04 (2-4)
Collect SS-03 (14-16)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-05
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/26/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/26/09
Boring Location: Near former storage shed	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	2.9	NA	0-1	Brown F-M SAND, some silt, some m-c gravel.
				1-2.9	Orange-brown F-M SAND and SILT, trace clay, trace f-m gravel.
				2.9-4	No Recovery.
4-8	4	3	NA	0-1	Orange-brown F-M SAND and SILT, trace f-m gravel.
				1-3	Orange-brown F-C SAND, trace f-m gravel.
				3-4	No Recovery.
8-12	4	3	NA	0-1.5	Orange-brown F-C SAND, trace-silt, trace f-m gravel.
				1.5-3	Orange-brown M-C SAND, trace f-c gravel.
				3-4	No Recovery.
12-16	4	2.3	NA	0-2.3	Orange-brown M-C SAND, trace f-c gravel, wet at 15.5-16 fbg.
				2.3-4	No Recovery.

Lithology



Legend

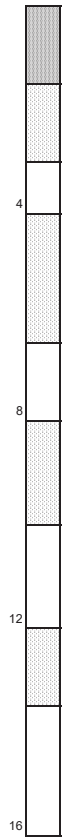
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-05 (5-7)
Collect SS-05 (13-15)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-06
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/26/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/26/09
Boring Location: Near former storage shed	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	2.9	NA	0-0.6	Gray-brown VF-FSAND and SILT, trace f-m gravel.
				0.6-1	Brown F-M SAND and SILT, trace f-m gravel.
				1-1.5	Orange-brown F-M SAND and SILT, trace clay, trace f-m gravel.
				1.5-2.9	Orange-brown F-M SAND, little silt.
				2.9-4	No Recovery.
4-8	4	2.5	NA	0-2.5	Orange-brown F-M SAND, trace silt, little m-c gravel.
				2.5-4	No Recovery,
8-12	4	2.2	NA	0-2.2	Orange-brown F-C SAND, little m-c gravel.
				2.2-4	No Recovery.
12-16	4	1.6	NA	0-1.6	Orange-brown F-C SAND, little m-c gravel, wet at 15.5-16 fbg.
				1.6-4	No Recovery.

Lithology



Legend

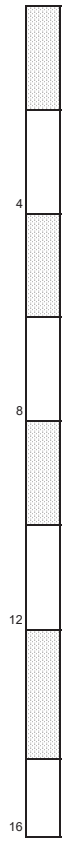
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-06 (1-3)
Collect SS-06 (14-16)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-07
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/26/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/26/09
Boring Location: Near former storage shed	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	2.1	NA	0-1	Dark brown F-M SAND, little silt, some m-c gravel.
				1-2.1	Orange-brown F-M SILTY SAND, little clay.
				2.1-4	No Recovery.
4-8	4	2.2	NA	0-0.5	Orange-brown F-M SILTY SAND, little clay.
				0.5-2.2	Orange-brown F-M SAND, little f-m gravel.
				2.2-4	No Recovery.
8-12	4	2.3	NA	0-1	Orange-brown F-M SAND, little f-m gravel.
				1-2.3	Orange-brown M-C SAND, little f-m gravel.
				2.3-4	No Recovery.
12-16	4	2.5	NA	0-2.5	Orange-brown M-C SAND, little f-m gravel. Wet at 15.5-16 fbg.
				2.5-5	No Recovery.

Lithology



Legend

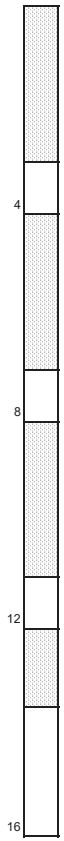
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-07 (6-8)
Collect SS-07 (13-15)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-08
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/26/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/26/09
Boring Location: Near former storage shed	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	3	NA	0-0.2	Dark brown F-M SAND, little m-c gravel.
				0.2-3	Orange-brown F-M SAND, some silt, trace clay, trace f-m gravel.
				3-4	No Recovery.
4-8	4	2.9	NA	0-2.9	Orange-brown F-M SAND, little silt, trace f-m gravel.
				2.9-4	No Recovery.
8-12	4	2.8	NA	0-2.8	Orange-brown F-M SAND, trace silt, trace f-gravel.
				2.8-4	No Recovery.
12-16	4	2.5	NA	0-1	Orange-brown F-M SAND, trace silt, trace f-gravel.
				1-2.5	Orange-brown M-C SAND, trace f-m gravel, wet at 15.5-16 fbg.
				2.5-4	No Recovery.

Lithology



Legend

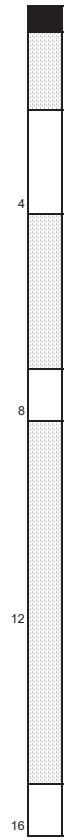
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-08 (3-4)
Collect SS-08 (12-14)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-09
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/26/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/26/09
Boring Location: Former lagoons	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	1.9	NA	0-0.5	TOPSOIL.
				0.5-1.9	Orange-brown F-C SAND, some silt, trace clay, some f-c gravel, very moist.
				1.9-4	No Recovery.
4-8	4	3.3	NA	0-3.3	Orange-brown F-M SAND, little silt, trace clay, little f-m gravel, very moist near bottom.
				3.3-4	No Recovery.
8-12	4	3.8	NA	0-1	Orange-brown F-M SAND, little silt, trace clay, little f-m gravel
				1-3.8	Orange-brown F-C SAND, little silt, trace f-m gravel.
				3.8-4	No Recovery.
12-16	4	3.1	NA	0-2	Orange-brown F-C SAND, trace silt, trace f-m gravel.
				2-3.1	Red-brown F-C SAND, trace f-m gravel, wet at 14-16 fbg.
				3.1-4	No Recovery.

Lithology



Legend

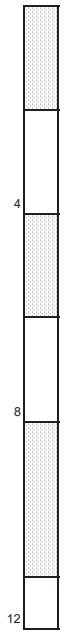
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-09 (6-8)
Collect SS-09 (12-14)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-10
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/26/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/26/09
Boring Location: Former lagoons	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	2	NA	0-1	Brown F-M SAND, some silt, little f-m gravel.
				1-2	Orange-brown F-M SAND, some silt, little f-m gravel.
				2-4	No Recovery.
4-8	4	2.2	NA	0-1	Orange-brown M-C SAND.
				1-2.2	F-M SAND, some silt, trace f-m gravel, wet at tip.
				2.2-4	No Recovery.
8-12	4	3.2	NA	0-3.2	Orange-brown F-C SAND, trace f-m gravel, wet.
				3.2-4	No Recovery.

Lithology



Legend

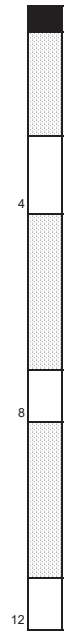
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-10 (2-4)
Collect SS-10 (4-6)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-11
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/27/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/27/09
Boring Location: Former lagoons	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	2.6	NA	0-0.4	TOPSOIL
				0.4-2.6	Orange-brown F-M SAND, some silt, little clay, trace f-m gravel.
				2.6-4	No Recovery.
4-8	4	2.8	NA	0-1	Orange-brown F-M SAND, some silt, little clay, trace f-m gravel.
				1-2	Orange-brown M-C SAND, trace silt, little f-m gravel.
				2-2.8	Tan F-M SAND.
				2.8-4	No Recovery.
8-12	4	3	NA	0-0.5	Tan F-M SAND.
				0.5-3	Orange-brown F-M SAND, some silt, trace clay, trace f-m gravel. Wet at 8-12 fbg.
				3-4	No Recovery.

Lithology



Legend

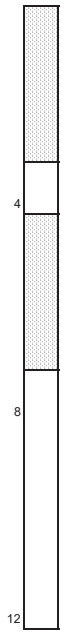
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-11 (1-3)
Collect SS-11 (5-7)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-12
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/27/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/27/09
Boring Location: Former lagoons	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	3	NA	0-1	Brown F-M SAND, little silt, trace f-m gravel.
				1-3	Orange-brown F-M SAND, little silt, little f-m gravel.
				3-4	No Recovery.
4-8	4	3	NA	0-0.5	Orange-brown F-M SAND, little silt, little f-m gravel.
				0.5-2.2	Orange-brown M-C SAND, little f-m gravel.
				2.2-3	Orange-brown F-M SAND, some silt, little clay. Wet at tip.
				3-4	No Recovery.
8-12	4	0	NA	0-4	No Recovery. Sleeve jammed inside macro-core. Wet.

Lithology



Legend

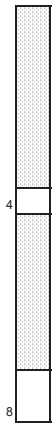
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-12 (2-4)
Collect SS-12 (5-7)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-13
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/27/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/27/09
Boring Location: Former lagoons	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	3.4	NA	0-1.2	Brown F-M SAND, little silt, little f-m gravel.
				1.2-3.4	Orange-brown F-M SAND, little silt, little f-m gravel.
				3.4-4	No Recovery.
4-8	4	2.9	NA	0-1.9	Orange-brown F-M SAND, little silt, little f-m gravel.
				1.9-2.9	Orange-brown m-c sand, little f-m gravel. Wet at bottom 0.2'
				2.9-4	No Recovery.

Lithology



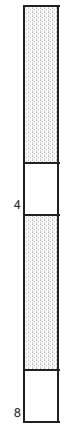
Legend

- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-13 (1-3)
Collect SS-13 (5-7)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-14
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/27/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/27/09
Boring Location: Former lagoons	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description	Lithology
0-4	4	3	NA	0-3	Brown F-M SAND, little silt, little f-m gravel.	
				3-4	No Recovery.	
4-8	4	3	NA	0-1	Brown F-M SAND, little silt, little f-m gravel.	
				1-3	Red brown M-C SAND, trace f-m gravel. Wet at bottom 0.2'	
				3-4	No Recovery.	



Legend

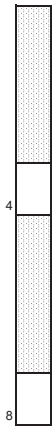
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-14 (1-3)
Collect SS-14 (6-8)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-15
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/27/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/27/09
Boring Location: Former lagoons	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	2.9	NA	0-1	Brown F-M SAND, little silt, little f-c gravel.
				1-1.1	C-GRAVEL.
				1.1-2.9	Orange-brown F-C SAND, little f-m gravel.
				2.9-4	No Recovery.
4-8	4	3.5	NA	0-0.5	Orange-brown F-C SAND, little f-m gravel.
				0.5-1.9	Orange-brown F-M SILTY SAND, some clay.
				1.9-3.5	Orange-brown F-M SAND, little silt. Wet at bottom 0.1'
				3.5-4	No Recovery.

Lithology



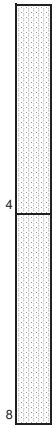
Legend

- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-15 (2-4)
Collect SS-15 (4-6)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-16
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/27/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/27/09
Boring Location: Former lagoons	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description	Lithology
0-4	4	4	NA	0-0.8	Dk. Brown F-M SAND, little silt	
				0.8-2.1	Brown F-M SAND, little silt, some f-c gravel.	
				2.1-4	Orange-brown F-M SAND, some silt, trace clay, little f-c gravel.	
4-8	4	4	NA	0-4	Orange-brown F-M SAND, some silt, trace clay. Wet at tip.	



Legend

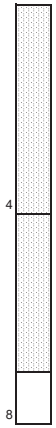
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-16 (1-3)
Collect SS-16 (6-8)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-17
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/27/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/27/09
Boring Location: Former lagoons	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	4	NA	0-2.5	Brown F-M SAND, little silt, little f-c gravel.
				2.5-4	Orange-brown F-M SAND, some silt, little clay, little f-m gravel.
4-8	4	3	NA	0-3	Orange-brown F-M SAND, some silt, little clay, little f-m gravel. Wet at bottom 0.5'
				3-4	No Recovery.

Lithology



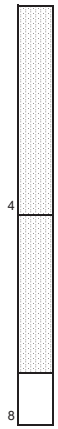
Legend

- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-17 (1-3)
Collect SS-17 (5-7)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-18
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/27/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/27/09
Boring Location: Former lagoons	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description	Lithology
0-4	4	4	NA	0-1.3	Dk. Brown F-M SAND, little silt, trace clay, trace f-m gravel.	
				1.3-4	Brown F-M SAND, some silt, little clay, trace f-c gravel.	
4-8	4	3	NA	0-0.5	Brown F-M SAND, some silt, little clay, trace f-c gravel.	
				2.5-3	Orange-brawn M-C SAND, little f-m gravel, red at bottom. Wet at bottom 0.2'	
				3-4	No Recovery.	



Legend

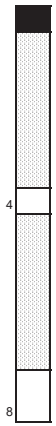
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-18 (1-3)
Collect SS-18 (6-8)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring: SS-19
Project Number: 171441.000050.000000	Drillers: Michael	Date Started: 10/27/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed: 10/27/09
Boring Location: Former lagoons	Drill Equipment / Method: Geoprobe 66DT	

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	3.5	NA	0-0.5	Dk. Brown F-M SAND, some silt (TOPSOIL).
				0.5-1.5	Orange-brown F-M SAND, little f-m gravel, trace silt.
				1.5-1.7	Brown-black F-M SAND
				1.7-2.6	Brown F-M SAND, little sitl, little f-m gravel.
				2.6-3.5	Orange-brown F-C SAND, little f-c gravel.
				3.5-4	No Recovery.
4-8	4	3.3	NA	0-0.8	Orange-brown F-M SAND, little silt, little clay
				0.8-3.3	Orange-brown m-c sand,some m-c Wet at bottom 0.5'
				3.3-4	No Recovery.

Lithology



Legend

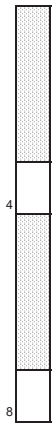
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-19 (1-3)
Collect SS-19 (6-8)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-20
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/27/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/27/09
Boring Location: Former lagoons	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	3.2	NA	0-2.4	Brown F-M SAND, trace silt. Little f-m gravel.
				2.4-2.6	Dense orange-brown F-SILTY SAND gravel, trace silt.
				2.6-3.2	Brown F-M SAND, some f-m gravel.
				3.2-4	No recovery.
4-8	4	3.2	NA	0-3.2	Brown F-M SAND, trace silt, little f-m gravel. Wet at tip.
				3.2-4	No Recovery.

Lithology



Legend

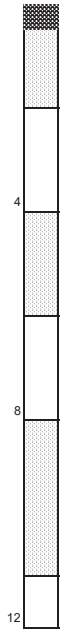
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-20 (1-3)
Collect SS-20 (4-6)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-21
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/28/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/28/09
Boring Location: Former Bldg. D102 footprint	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	1.4	NA	0-0.5	Concrete
				0.5-1	Brown F-M SAND, little f-m gravel.
				1-1.9	Orange-brown M-C SAND, little f-m gravel.
				1.9-4	No Recovery.
4-8	4	2.3	NA	0-2.3	Orange-brown M-C SAND, little m-c gravel. Wet at tip.
				2.3-4	No Recovery.
8-12	4	3	NA	0-1	Orange-brown F-M SAND, some silt, trace f-m gravel. Wet.
				1-3	Orange-brown F-M SAND. Wet.
				3-4	No Recovery.

Lithology



Legend

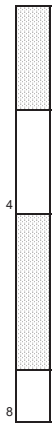
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- Concrete
- No Recovery

Collect SS-21 (1-3)
Collect SS-21 (5-7)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-22
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/28/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/28/09
Boring Location: Former Bldg. D102 footprint	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	2.1	NA	0-0.6	Brown F-M SAND, some f-m gravel, little silt.
				0.6-0.9	Orange-brown F-M SAND.
				0.9-1.2	Black F-M SAND, petro odor.
				1.2-2.1	Brown F-M SAND, little silt, little f-m gravel.
				2.1-4	No recovery.
4-8	4	3.1	NA	0-0.6	Brown F-M SAND, little silt, little f-m gravel.
				0.6-3.1	Orange-brown M-C SAND, little f-m gravel. Wet at tip.
				3.1-4	No recovery.

Lithology



Legend

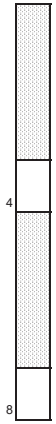
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-22 (1-3)
Collect SS-22 (6-8)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-23
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/28/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/28/09
Boring Location: Former Bldg. D102 footprint	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	2.9	NA	0-0.6	Brown F-M SAND, some m-c gravel and concrete fragments.
				0.6-1.6	Orange-brown F-M SAND, little f-m gravel.
				1.6-2.9	Dk. Brown F-M SAND, little silt.
				2.9-4	No recovery.
4-8	4	3.3	NA	0-0.6	Orange-brown M-C SAND, little f-m gravel. Wet at tip.
				3.3-4	No recovery.

Lithology



Legend

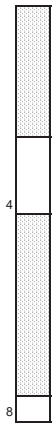
- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-23 (2-4)
Collect SS-23 (6-8)

Project Name: SMC Off-Site Ground Water Investigation	Drilling Company: Unitech Drilling Co., Inc.	Boring:	SS-24
Project Number: 171441.000050.000000	Drillers: Michael	Date Started:	10/28/09
Project Location: Newfield, NJ	TRC Inspector: John Moss	Date Completed:	10/28/09
Boring Location: Former Bldg. D102 footprint	Drill Equipment / Method: Geoprobe 66DT		

Depth (feet)	Penetration (ft)	Recovery (ft)	PID (ppm)	(ft)	Soil Description
0-4	4	2.5	NA	0-0.9	Black-Brown F-M SAND, little c-sand, some f-c gravel and concrete fragments.
				0.9-1.6	Orange-brown F-M SAND, little f-m gravel.
				1.6-1.8	Black gravel.
				1.8-2.5	Brown F-M SAND, little f-m gravel.
				2.5-4	No recovery.
4-8	4	3.3	NA	0-1.4	Brown F-M SAND, little f-m gravel.
				1.4-3.3	Orange-Brown F-M SAND, some silt, little clay. Wet at tip.
				3.3-4	No recovery.

Lithology



Legend

- Topsoil
- Sand
- Silty Clay
- Gravel
- Sand and Silt
- Ash
- No Recovery

Collect SS-24 (1-3)
Collect SS-24 (4-6)

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: Whale pump
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-13 (25-30')
Date: 10/14/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 11:05 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
11:10				4.62	0.138	986.1	8.02	12.97		242.0	Orange-brown, silty
11:14				4.42	0.141	614.8	8.13	12.93		267.0	Orange-brown, silty
11:17				4.34	0.144	461.0	8.23	12.90		281.9	Orange-brown, silty
11:21				4.32	0.147	321.0	8.30	12.88		288.8	Orange-brown, silty
11:26				4.33	0.150	219.3	8.40	12.85		295.6	Orange-brown, silty
11:30				4.30	0.152	128.2	8.47	12.85		297.4	Orange-brown, silty
11:35				4.31	0.153	57.3	8.59	12.82		302.3	Clear
3@3-5 m.			30-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-13 (25-30') Sample Time: 11:35 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Containers Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-13 (50-55')
Date: 10/14/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 13:14 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
13:17				5.18	0.171	1086.4	2.97	14.09		208.5	Orange-brown, silty
13:20				4.78	0.174	1035.5	3.11	13.96		227.1	Orange-brown, silty
13:23				4.62	0.175	506.4	2.69	13.82		245.5	Orange-brown, silty
13:26				4.60	0.174	284.8	2.44	13.67		252.8	Orange-brown, silty, clearing
13:29				4.62	0.176	177.0	2.35	13.63		257.8	Orange-brown, silty, clearing
13:32				4.61	0.176	97.7	2.28	13.57		266.9	Orange-brown, silty, clearing
13:37				4.62	0.176	59.5	2.28	13.52		269.4	Slightly cloudy
13:45				4.65	0.175	46.9	2.17	13.44		277.6	Slightly cloudy
3@3-5 m.			~100-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-13 (50-55') Sample Time: 13:45 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Containers Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-13 (75-80')
Date: 10/14/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 14:40 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
14:43				4.48	0.131	408.0	6.41	14.19		245.7	Slight orange-brown, silty
14:48				4.46	0.125	26.8	7.36	14.20		269.8	clear
14:53				4.41	0.125	8.2	7.50	14.16		287.0	clear
3@3-5 m.			~70-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-13 (75-80') Sample Time: 14:55 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Containers Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-13 (100-105')
Date: 10/15/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 8:28 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
8:31				5.70	0.148	1109.7	3.18	13.81		96.2	Orange-brown, silty
8:36				5.34	0.122	321.4	6.61	14.09		153.7	Orange-brown, silty
8:41				5.14	0.117	528.5	7.62	14.18		183.2	Orange-brown, silty
8:46				5.02	0.115	328.5	7.87	14.21		200.6	Orange-brown, silty
8:51				4.88	0.113	274.6	8.05	14.00		218.4	Orange-brown, silty
8:56				4.77	0.113	166.7	8.13	13.98		232.0	Orange-brown, silty
9:01				4.74	0.113	99.4	8.16	13.98		240.4	Slightly cloudy
9:06				4.71	0.113	54.3	8.18	13.99		247.0	Slightly cloudy
9:11				4.68	0.113	35.4	8.20	13.99		252.4	Clear
3@3-5 m.			~100-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-13 (100-105') Sample Time: 9:15 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Containers Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-13 (125-130')
Date: 10/15/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information — Start purge at: 10:32 — Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
10:37				6.22	0.039	1113.1	8.08	14.18		208.6	Orange-brown, silty
10:42				5.13	0.035	718.5	8.50	14.19		223.3	Orange-brown, silty
10:45 - 10:49	Not pumping										
10:52				5.14	0.034	1085.0	8.39	14.17		222.7	Orange-brown, silty
10:56 - 11:22	Not pumping										
11:25				5.22	0.034	500.8	8.24	14.10		213.2	Orange-brown, silty
11:30				5.13	0.033	116.9	8.40	14.14		226.8	Slightly cloudy
11:34				5.09	0.033	50.1	8.42	14.15		231.9	Clear
11:38				5.05	0.033	15.1	8.44	14.16		235.6	Clear
3@3-5 m.			~100-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information — Sample Identity: VP-13 (125-130') — Sample Time: 11:40 — TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather: ~50-degrees, cloudy
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: Vp-13A (15-20')
Date: 10/22/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information — Start purge at: 11:58 — Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
12:04				4.63	0.387	1414.6	1.59	18.43		192.8	Orange-brown, silty
12:07 - 12:09	Not Pumping										
12:13				4.72	0.436	1420.2	0.86	18.90		199.1	Orange-brown, silty
12:15				4.68	0.447	1065.2	0.62	18.86		205.0	Orange-brown, silty
12:20				4.67	0.454	290.1	0.58	18.91		208.1	Cloudy
12:24				4.69	0.458	197.5	0.47	19.00		208.1	Slightly Cloudy
12:28				4.71	0.460	107.3	0.47	19.10		206.3	Clear
12:35				4.73	0.462	44.2	0.43	19.17		205.2	Clear
3@3-5 m.			~50-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information — Sample Identity: VP-13A (15-20') — Sample Time: 12:35 — TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Containers Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather: ~60-degrees, sunny
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-13A (37-42')
Date: 10/22/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 14:03 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
14:06				4.52	0.186	181.6	0.40	14.75		154.9	Slightly orange-brown, silty
14:11				4.44	0.183	42.7	0.25	14.56		197.4	Clear
14:14				4.42	0.182	32.8	0.23	14.50		213.9	Clear
3@3-5 m.			~80-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-13A (37-42') Sample Time: 14:15 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Containers Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-13A (62-67')
Date: 10/22/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 15:06 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
15:13				4.62	0.148	1215.2	0.29	16.44		174.7	Orange-brown, silty
15:50				4.80	NA	3.7	NA	NA		NA	Clear
3@3-5 m.			~70-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-13A (62-67') Sample Time: 15:50 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather: ~55-degrees, cloudy
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-13A (87-92')
Date: 10/23/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 8:28 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
8:31				5.65	0.115	471.2	3.02	14.37		52.7	Orange-brown, silty
8:35				4.84	0.100	95.1	5.31	14.27		127.4	Clear
8:38				4.76	0.100	107.7	5.30	14.25		145.3	Clear
8:41				4.67	0.100	55.7	6.20	14.22		161.6	Clear
8:46				4.61	0.100	42.4	6.25	14.21		181.5	Clear
8:50				4.56	0.100	27.8	6.62	1.20		197.3	Clear
8:52				4.55	0.100	26.3	6.60	14.19		201.2	Clear
3@3-5 m.			~125-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-13A (87-92') Sample Time: 8:55 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather: ~60-degrees, cloudy
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-13A (111-116')
Date: 10/26/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 9:57 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
10:00				5.27	0.058	1374.0	5.41	14.64		133.5	Orange-brown, silty
10:06				4.87	0.039	138.7	7.47	14.60		181.1	Cloudy
10:11				4.85	0.038	38.9	7.62	14.54		191.6	Clear
10:15				4.87	0.037	18.5	7.67	14.50		198.2	Clear
10:17				4.88	0.037	15.1	7.70	14.49		200.7	Clear
3@3-5 m.			~75-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-13A (111-116') Sample Time: 10:20 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: Whale pump
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-14 (35-40')
Date: 10/16/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 12:00 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
12:27				5.20	0.188	1109.0	4.55	13.64		234.8	Orange-brown, silty
12:32				4.90	0.181	1074.6	5.48	14.30		232.5	Orange-brown, silty
12:40				4.76	0.215	581.0	3.16	14.81		224.4	Orange-brown, silty
12:45				4.73	0.228	487.7	2.97	14.84		215.0	Orange-brown, silty
12:49				4.73	0.237	530.0	2.90	14.85		208.9	Orange-brown, silty
12:53				4.73	0.242	408.8	2.90	14.90		197.5	Orange-brown, silty
13:00				4.74	0.248	254.6	2.91	14.94		189.6	Cloudy
13:06				4.76	0.252	180.0	2.87	14.94		177.5	Slightly cloudy
3@3-5 m.			~75-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-14 (35-40') Sample Time: 13:10 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Containers Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-14 (55-60')
Date: 10/16/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 13:50 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
13:53				4.75	0.090	487.4	7.46	14.23		249.3	Cloudy, orange-brown silt
13:57				4.70	0.087	182.2	7.56	14.70		246.3	Cloudy
14:03				4.67	0.086	52.3	7.73	14.83		249.5	Clear
14:06				4.65	0.085	43.7	7.82	14.80		253.3	Clear
14:09				4.62	0.084	46.0	7.94	14.60		256.3	Clear
14:13				4.60	0.085	36.4	8.01	14.59		260.9	Clear
3@3-5 m.			~50-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-14 (55-60') Sample Time: 14:15 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Containers Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-14 (130-135')
Date: 10/19/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 14:40 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
14:51				4.77	0.065	209.8	3.73	14.39		207.6	Cloudy, orange-brown silt
14:56				4.70	0.063	99.0	3.72	14.36		228.3	Slightly cloudy
14:58				4.68	0.062	77.3	3.71	14.35		235.5	Clear
15:01				4.66	0.062	64.6	3.70	14.36		242.0	Clear
15:05				4.60	0.061	58.3	3.68	14.32		249.5	Clear
15:07				4.60	0.061	55.0	3.67	14.32		251.6	Clear
3@3-5 m.			~100-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-14 (130-135') Sample Time: 15:10 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-15 (30-35')
Date: 10/12/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 14:03 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
14:15				8.60	0.124	1147.2	19.15	18.16		146.0	Yellow-brown, silty
14:24				5.87	0.129	1007.1	9.53	18.96		194.8	Yellow-brown, silty
14:28				5.27	0.121	135.2	8.51	18.01		229.8	Pale yellow
14:31				5.06	0.120	75.6	8.56	17.97		243.3	Pale yellow
14:34				4.94	0.119	48.7	8.53	17.94		254.2	Pale yellow
3@3-5 m.			~75-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-15 (30-35') Sample Time: 14:40 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Containers Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-15 (45-50')
Date: 10/12/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 15:26 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
15:29				4.96	0.074	284.0	2.80	17.31		240.3	
15:31				4.89	0.072	114.1	2.79	17.21		245.2	
15:34				4.83	0.071	33.3	2.79	17.10		256.7	
3@3-5 m.			~50-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-15 (45-50') Sample Time: 15:35 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Containers Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-15 (65-70)
Date: 10/13/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 9:00 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
9:05				5.07	0.073	82.5	4.54	16.48		202.2	Yellow, silty, then clearing
9:08				4.94	0.072	29.8	4.78	16.43		215.9	Slightly yellow, silty
9:11				4.82	0.072	18.1	4.85	16.40		232.0	Clear
9:14				4.72	0.072	9.6	4.87	16.38		246.3	Clear
3@3-5 m.			~50-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-15 (65-70') Sample Time: 9:15 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-15 (88-93')
Date: 10/13/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 10:24 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
10:26				5.11	0.066	1129.0	4.52	16.13		210.8	Yellow-brown, silty
10:29				4.90	0.062	317.8	5.03	15.76		234.5	Yellow-brown, silty
10:31				4.77	0.061	141.8	5.31	15.59		250.5	Yellow-brown, silty, clearing
10:34				4.66	0.059	72.9	5.40	15.46		265.3	Slightly silty
10:38				4.61	0.059	42.4	5.64	15.35		281.1	Slightly silty
3@3-5 m.			~100-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-15 (88-93') Sample Time: 10:40 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Containers Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-15 (114-119')
Date: 10/13/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 11:50 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
11:54				4.50	0.037	1112.3	0.50	17.05		100.0	Gray, silty
11:58				4.30	0.033	668.2	0.41	17.04		97.8	Gray, silty
12:02				4.19	0.034	225.3	0.36	17.00		104.1	Gray, silty
12:05				4.14	0.036	92.1	0.36	16.93		104.9	Gray, slightly silty
12:08				4.13	0.036	55.4	0.35	16.88		106.4	Gray, slightly silty
12:13				4.15	0.036	65.2	0.32	16.83		107.7	Gray, slightly silty
3@3-5 m.			~50-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-15 (114-119') Sample Time: 12:15 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Containers Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: Whale pump
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-15A (15-20')
Date: 10/20/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 15:05 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
15:09				5.73	0.554	165.3	5.92	17.48		122.1	Orange-brown, silty, slightly cloudy
15:14				5.64	0.560	118.1	6.01	17.44		119.7	Orange-brown, silty, slightly cloudy
15:18				5.62	0.564	85.2	5.94	17.42		112.7	Orange-brown, silty, slightly cloudy
15:23				5.60	0.525	265.4	5.62	17.37		114.5	Orange-brown, silty
15:28				5.59	0.554	112.0	5.63	17.34		128.5	Slightly cloudy
15:31				5.58	0.524	55.7	5.64	17.29		132.9	Clear
15:39				5.56	0.518	34.1	5.77	17.28		131.0	Clear
3@3-5 m.			~50-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-15A (15-20') Sample Time: 15:40 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Containers Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather: ~55-degrees, sunny
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-15A (38-43')
Date: 10/21/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 8:36 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
8:39				4.98	0.084	656.3	3.92	13.99		148.9	Orange-brown, silty
8:42				4.85	0.084	92.5	3.88	14.48		181.8	Clear
8:45				4.80	0.084	79.1	3.92	14.50		196.8	Clear
8:50				4.75	0.084	44.6	4.01	14.53		214.3	Clear
3@3-5 m.			~100-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-15A (38-43') Sample Time: 8:50 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Containers Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather: ~60-degrees, sunny
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-15A (55-60')
Date: 10/21/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 9:45 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
9:48				4.58	0.051	1377.4	3.84	15.01		199.9	Orange-brown, silty
9:53				4.49	0.050	220.7	4.14	14.62		237.7	Cloudy
10:20				4.52	0.049	43.0	4.20	14.44		268.5	Clear
3@3-5 m.			~125-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-15A (55-60') Sample Time: 10:20 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather:
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-15A (77-82')
Date: 10/21/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 11:16 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
11:18				4.91	0.050	209.3	4.72	15.24		188.0	Orange-brown, silty
11:21				4.52	0.047	79.0	5.62	14.82		230.9	Orange-brown, slightly silty
11:25				4.37	0.047	62.0	5.86	14.59		255.3	Slightly cloudy, then clear
11:27				4.39	0.046	90.0	5.72	14.83		261.1	Clear
3@3-5 m.			~50-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-15A (77-82') Sample Time: 11:30 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Containers Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Ground Water Sampling Log

Client: SMC
Project Number: 112434.00GWAT.002235
Site Name / Location: SMC / Newfield / Off-site locations in Vineland
Site Conditions / Weather: ~65-degrees, sunny
Purge Method: SAT & submersible pump / packer assembly
Purge Equipment/Material: SAT
Headspace PID/FID (ppm): NA
Pump Intake (ftbtoc):

Well Identification: VP-15A (99-104')
Date: 10/21/2009
Depth to Water (ftbtoc): NA
Depth to Bottom (ftbtoc): NA
Standing Column (ft): NA
Well Diameter (in): 4.25"
Standing Volume (gal,liter): NA
Screened Interval (ftbtoc):

Purging Information Start purge at: 13:40 Well Casing Volumes: 1" = 0.04 gal/ft = 0.15 L/ft, 2" = 0.16 gal/ft = 0.62 L/ft, 4" = 0.65 gal/ft = 2.47 L/ft, 6" = 1.47 gal/ft = 5.56 L/ft

Time	DTW (ftbtoc)	Purge Rate (gpm,lpm)	Volume Purged (gal,liter)	pH	Specific Cond. (mS/cm)	Turbidity (NTU)	Dissolved Oxygen (mg/L)	Temp. (ºC)	Other	ORP (mV)	Comments / Observations (color, odor, etc.)
13:44				4.21	0.056	1380.3	5.53	15.31		199.2	Orange-brown, silty
13:47				3.73	0.055	72.4	6.38	14.82		248.3	Cloudy
13:50				3.68	0.055	22.0	6.51	14.56		261.6	Clear
13:54				3.67	0.054	9.2	6.60	14.37		271.6	Clear
3@3-5 m.			~110-gal	+/- 0.1	3%	10%	10%	3%		+/- 10 mV	

Sampling Information Sample Identity: VP-15A (99-104') Sample Time: 13:55 TRC Personnel: J. Moss

Analysis	Containers Number	Containers Size	Containers Type	Preservative	Sampling Method/Material	Comments / Observations
VOCs						
Total Cr						
Cr+6						
Perchlorate						
Methane						
Nitrate						
Fe+2						

Supplemental Offsite Groundwater Investigation
Shieldalloy Metallurgical Corporation
Newfield, New Jersey

SOIL BORING / MONITORING WELL CONSTRUCTION LOG

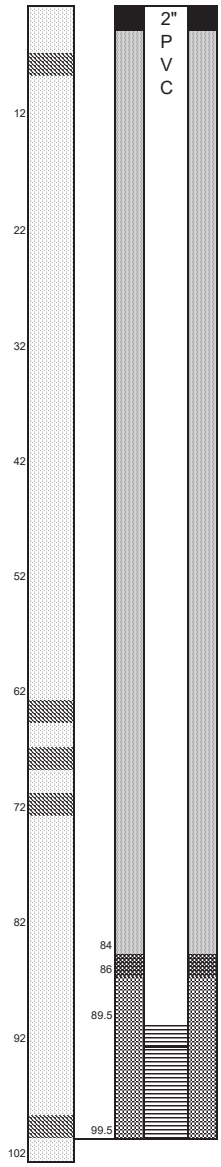
Project Name: SMC Offsite Ground Water Investigation
Project Number: 112434-00GWAT-002235
Project Location: Vineland, New Jersey
Boring Location: West Garden Road

Drilling Company: Unitech Drilling Co., Inc.
Drillers: Dan Evans and Joe Evans
TRC Inspector: Paul Cyr
Drill Equipment / Method: 1500 Midway Truck Rig
Mud Rotary / Pressure Tremie

Boring: SC-35D
Date Started: 10/29/2009
Date Completed: 10/29/2009
Depth to Water: NA
Horizontal Coordinates: E335051.78, N251029.52 (VP-15A)
Ground Elevation: NA
Inner Casing Elevation: NA

Depth (ftbgs)	Recovery/ Penetration (inches)	Split Spoon (inches)	Blow Counts	Soil Description
10-12	20/24	6	10	Light brown F SAND, trace M Sand
		12	14	and M Gravel
		18	15	Gray CLAY, trace C Gravel
		24	17	
20-22	8/18	6	25	Light brown F-M SAND, trace C
		12	30	Gravel
		18	50/5"	Spoon refusal at 21.5-ftbgs.
30-32	12/18	6	30	Light brown/orange F-M SAND,
		12	35	trace C Sand, trace F-M gravel
		18	50-5"	Spoon refusal at 31.5-ftbgs.
40-42	11/24	6	10	Red/orange/brown M-C SAND,
		12	15	little M-C Gravel, trace F sand
		18	19	and F gravel
		24	17	
50-52	20/20	6	24	Dark red/brown F SAND
		12	36	C GRAVEL, trace M Gravel
		18	50/7"	Spoon refusal at 51.7-ftbgs.
60-62	11/24	6	14	Gray CLAY and inter-bedded
		12	10	red/brown F SAND
		18	22	
		24	24	
70-72	9.5/18	6	10	Light brown F SAND, inter-bedded
		12	31	thin Clay layers
		18	50/5"	Red-brown F SAND, inter-bedded
				thin Clay layers
				Spoon refusal at 71.5-ftbgs.
80-82	11/24	6	15	Light brown F SAND, inter-bedded
		12	25	thin Silt layers
		18	36	
		24	40	
90-92	12/24	6	9	Light brown F SAND, trace C
		12	8	Gravel
		18	18	
		24	22	
100-102	19/24	6	10	Light brown F SAND, inter-bedded
		12	11	thin Clay layers
		18	13	
		24	15	

Lithology / Monitoring Well Construction



Legend
- Sand
- Sand and Clay
- # 0 Well Sand
- # 00 Well Sand
- Grout
- Screen (10-slot PVC)
- Concrete Pad
- PVC Riser

WELL CONSTRUCTION:
- 10-Slot PVC Screen (2") = 99.5-89.5 ftbgs
- PVC Riser (2") = 89.5 ftbgs-grade
- # 0 Well Sand = 99.5-86 ftbgs
- #00 Well Sand = 86-84 ftbgs
- Grout (bentonite/cement mixture) = 84-2 ftbgs
- Native Backfill = 2-0.5 ftbgs
- Concrete Pad = 0.5-grade
- Monitoring well secured with a locking sanitary plug.
- Monitoring well completed with a flush-mounted curb box.

NOTES:
- ftbgs - feet below ground surface.
- NA - Data not available at time of reporting.
- Horizontal datum (New Jersey State Plane Coordinates, NAD 83).
- Samples collected for geological description every 10 feet using split spoon (140 lb hammer dropped 30").
- Monitoring well developed using whale pumps in series and using surge and pump technique.

Supplemental Offsite Groundwater Investigation
Shieldalloy Metallurgical Corporation
Newfield, New Jersey

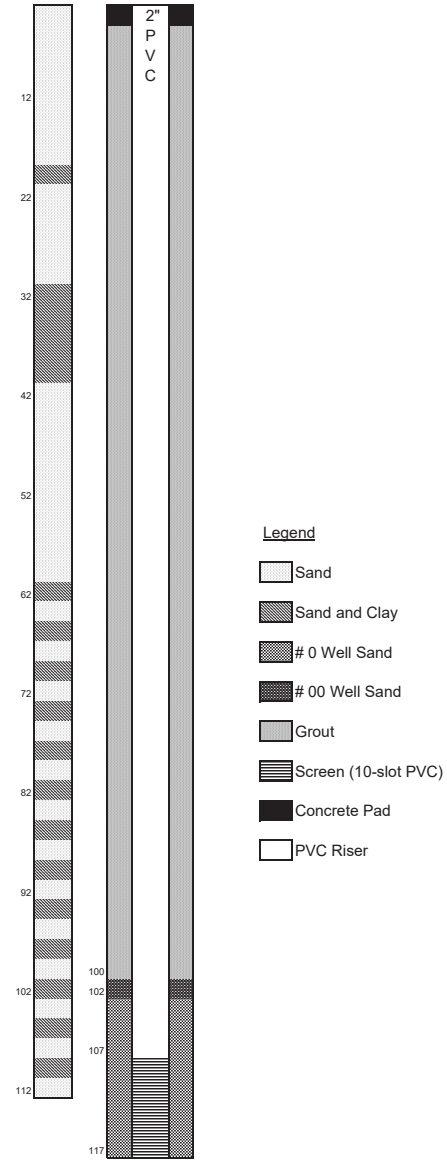
SOIL BORING / MONITORING WELL CONSTRUCTION LOG

Project Name: SMC Offsite Ground Water Investigation
Project Number: 112434-00GWAT-002235
Project Location: Vineland, New Jersey
Boring Location: Salem Avenue

Drilling Company: Unitech Drilling Co., Inc.
Drillers: Dan Evans and Joe Evans
TRC Inspector: Paul Cyr
Drill Equipment / Method: 1500 Midway Truck Rig
Mud Rotary / Pressure Tremie

Boring: SC-36D
Date Started: 11/3/2009
Date Completed: 11/4/2009
Depth to Water: NA
Horizontal Coordinates: E341283.30, N258484.52 (VP-13A)
Ground Elevation: NA
Inner Casing Elevation: NA

Depth (ftbgs)	Recovery/ Penetration (inches)	Split Spoon (inches)	Blow Counts	Soil Description
10-12	11/24	6	12	Red/orange/brown M-C SAND, trace
		12	16	C Gravel
		18	26	Red-brown M-C SAND
		24	29	Light brown - red-brown F SAND
20-22	8/24	6	16	Medium brown F SAND, thin Clay
		12	18	layer at 20-ftbgs.
		18	17	
		24	17	
30-32	24/24	6	22	Cobbles
		12	24	Red-brown F SAND
		18	17	Tan CLAY
		24	18	
40-42	15.5/24	6	20	Tan CLAY
		12	20	Red-brown F-M SAND
		18	29	
		24	37	
50-52	8/11	6	36	Red-brown M-C SAND, little M
		12	50/5"	Gravel, trace clay, trace C gravel
				Spoon refusal at 51-ftbgs.
60-62	23/24	6	13	Tan-medium brown CLAY, trace
		12	8	F Sand
		18	14	Medium brown F SAND
		24	20	Tan CLAY, trace F Sand
				Red-brown F SAND, trace clay
				Medium to light brown F SAND
70-72	19/24	6	8	Gray-brown CLAY and F SAND
		12	10	Medium brown F SAND, trace Clay
		18	7	Red-brown F SAND
		24	8	CLAY, trace F Sand
80-82	19/24	6	13	Tan CLAY
		12	7	Medium brown F SAND, trace Clay
		18	14	
		24	20	
90-92	14/24	6	16	Medium brown F SAND, trace Clay
		12	9	
		18	15	
		24	23	
100-102	18/24	6	13	Tan CLAY, trace M Gravel
		12	18	Red-brown F SAND, trace Clay
		18	26	
		24	26	
105-107	12/24	6	18	Cobbles, trace F Sand
		12	20	Tan CLAY, trace F Sand
		18	23	Red-brown F SAND, trace M Gravel,
		24	30	trace clay
110-112	12/24	6	9	Medium brown F SAND, trace Clay
		12	9	
		18	15	
		24	23	



WELL CONSTRUCTION:
- 10-Slot PVC Screen (2") = 117-107 ftbgs
- PVC Riser (2") = 107 ftbgs-grade
- # 0 Well Sand = 117-102 ftbgs
- #00 Well Sand = 102-100 ftbgs
- Grout (bentonite/cement mixture) = 100-1 ftbgs
- Native Backfill = 1-0.5 ftbgs
- Concrete Pad = 0.5-grade
- Monitoring well secured with a locking sanitary plug.
- Monitoring well completed with a flush-mounted curb box.

NOTES:
- ftbgs - feet below ground surface.
- NA - Data not available at time of reporting.
- Horizontal datum (New Jersey State Plane Coordinates, NAD 83).
- Samples collected for geological description every 10 feet using split spoon (140 lb hammer dropped 30").
- Monitoring well developed using whale pumps in series and using surge and pump technique.

TRC
Results you can rely on
21 Griffin Road North
Windsor, CT 06095
Telephone: 860-298-9692
Fax: 860-298-6399

BORING/WELL NUMBER: **SC40D**

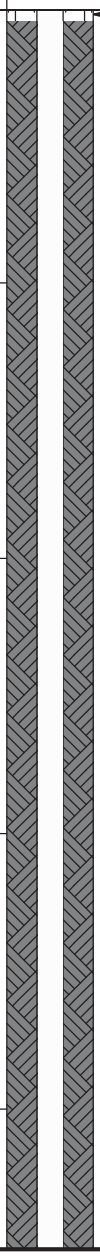
PROJECT INFORMATION		BORING/WELL INFORMATION			
Project Name:	Perchlorate RI	Boring Depth:	142	Hole Diameter:	4.25
Project Location:	Between 540 and 560 Salem Avenue, Vineland, NJ	Date Started:	4/4/11	Date Completed:	4/5/11
Project Number:	177208.0000.000003	Coordinate System:	New Jersey State Plane, NAD 83		
Client:	SMC	North:	258986	East:	342114
TRC Eng./Geol:	John Moss	Vertical Datum:	NAVD88	Ground Elevation:	97
Checked By:	Larry Butlien	Well Elevation (Top of Casing)	96.91 ft.		

DRILLING INFORMATION	
Drilling Contractor:	Uni-Tech Drilling
Driller(s):	Michael
Drilling Method:	Mud Rotary
Equipment/Model:	Failing 1500
Sampler:	2" split spoon

GROUND WATER OBSERVATIONS			
MEASUREMENT	At Time of Drilling	At End of Drilling	After Drilling
DATE			4/5/2011
DEPTH (ft.bgs.)			14.5
REFERENCE			Ground Surface
STABILIZATION			

DEPTH (FT.)	SAMPLE NUMBER	SAMPLE TYPE	PENETRATION (FT.)	RECOVERY (FT.)	BLOW COUNTS	LITHOLOGY	VOC SCREENING RESULTS (ppm) (20 40 60 80)	MATERIAL DESCRIPTION
11–12	SS-1	X	2.0	1.5	14 20 22 23			Yellow-Brown Very Fine-Medium SAND, trace Gravel; thin band of Silty Sand at 10.5'
21–22	SS-2	X	2.0	1.3	20 36 34 36			Yellow-Brown Very Fine-Fine SAND; coarse Gravel at top of recovery
31–32	SS-3	X	2.0	0.8	15 22 27 32			Yellow-Brown Very Fine-Coarse SAND; coarse Gravel at top of recovery
41–42	SS-4	X	2.0	1.1	34 38 50 56			Yellow-Brown Very Fine-Coarse SAND, trace fine Gravel; coarse Gravel at top of recovery; thin Light Gray Clay lens at 41.5'

WELL DIAGRAM



SOIL BORING / WELL COMPLETION - TRC-STD US.GDT - 6/20/11 14:40 - H:\HAZMAT\SMC\NEWFIELD\PERCHLORATE\PERCHLORATE RI\ADDITIONAL WELL INSTALL - SC40D\SMC PERCHLORATE - SC40D.GPJ

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TRC Eng./Geol:	John Moss	Vertical Datum:	NAVD88	Ground Elevation:	97
Checked By:	Larry Butlien	Well Elevation (Top of Casing)	96.91 ft.		

DEPTH (FT.)	SAMPLE NUMBER	SAMPLE TYPE	PENETRATION (FT.)	RECOVERY (FT.)	BLOW COUNTS	LITHOLOGY	VOC SCREENING RESULTS (ppm) (20 40 60 80)	MATERIAL DESCRIPTION	WELL DIAGRAM
46–50									
51–52	SS-5	X	1.4	0.8	45 50 50/5"			Yellow-Brown Very Fine-Medium SAND with some medium-coarse Gravel	
53–60								Brown Fine-Coarse SAND	Portland cement / bentonite grout mix
61–62	SS-6	X	2.0	0.8	32 32 30 26			Light Tan Very Fine-Medium SAND	
63–70								Red-Brown Very Fine-Coarse SAND; coarse Gravel at top of recovery	
71–72	SS-7	X	1.3	0.9	30 50 50/4"			Light Tan Fine-Medium SAND	
73–80									
81–82	SS-8	X	1.3	0.7	24 29 50/4"			Light Tan Very Fine-Fine SAND	
83–90								Yellow-Brown Very Fine-Fine SAND with trace Light Gray Clay lenses	
91	SS-9	X	0.9	0.6	30 50/5"			Tan Very Fine-Fine SAND	
92–95									

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Checked By:	Larry Butlien	Well Elevation (Top of Casing)	96.91 ft.		

DEPTH (FT.)	SAMPLE NUMBER	SAMPLE TYPE	PENETRATION (FT.)	RECOVERY (FT.)	BLOW COUNTS	LITHOLOGY	◆ VOC SCREENING RESULTS (ppm) (20 40 60 80)	MATERIAL DESCRIPTION	WELL DIAGRAM
97, 98, 99, 100									
101	SS-10		0.4	0.4	50/5"			Yellow-Brown Very Fine-Medium SAND with little Light Gray Clay lenses	
102, 103, 104, 105									
106	SS-11		0.9	0.6	24 50/5"			Yellow-Brown Very Fine-Medium SAND	
107, 108, 109, 110								Yellow-Brown Very Fine-Medium SAND with little Light Gray Clay lenses and Dark Brown/Red-Brown lenses	
111	SS-12		0.4	0.4	50/5"			Tan Very Fine-Medium SAND, some Light Gray Clay at top of recovery	
112, 113, 114, 115									
116	SS-13		1.3	0.8	22 28 50/4"			Yellow-Brown Very Fine-Medium SAND, little medium Gravel	#00 Sand
117, 118, 119, 120									#1 Sand
121	SS-14		2.0	0.8	20 24 30 57			Yellow-Brown Very Fine-Medium SAND, little Light Gray Clay and coarse Sand at top of recovery	
122, 123, 124, 125									
126	SS-15		0.8	0.4	30 50/4"			Orange-Brown Fine-Coarse SAND	2" Sch. 40 0.01" slot PVC Well Screen
127, 128, 129, 130									
131	SS-16		2.0	0.8	20 26 46 50			Tan Very Fine-Fine SAND, little fine Gravel, little Light Gray Clay	Threaded 2" PVC bottom cap
132, 133, 134, 135									
136	SS-17		1.7	1.0	24 34 55 17/2"			Tan Fine-Coarse SAND, trace Light Gray Clay lenses	
137, 138, 139, 140								Orange-Brown Very Fine-Fine SAND, some Light Gray Clay lenses	
141	SS-18		2.0	1.0	16 21 31 23			Orange-Brown Very Fine-Medium SAND with some fine Gravel	
142, 143, 144, 145, 146								Bottom of borehole at 142.0 feet.	

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