ANNUAL GROUNDWATER MONITORING
SAMPLING AND ANALYSIS PLAN

BP TERMINAL 22T
9930 NW ST. HELENS ROAD
PORTLAND, OREGON

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<table>
<thead>
<tr>
<th>Abbreviation</th>
<th>Full Form</th>
</tr>
</thead>
<tbody>
<tr>
<td>ARC</td>
<td>Atlantic Richfield Company</td>
</tr>
<tr>
<td>BP</td>
<td>British Petroleum</td>
</tr>
<tr>
<td>BTEX</td>
<td>benzene, toluene, ethylbenzene, xylenes</td>
</tr>
<tr>
<td>°C</td>
<td>degrees Celsius</td>
</tr>
<tr>
<td>CMT</td>
<td>continuous multichannel tubing</td>
</tr>
<tr>
<td>COPC</td>
<td>constituent of potential concern</td>
</tr>
<tr>
<td>CPD</td>
<td>City of Portland vertical datum</td>
</tr>
<tr>
<td>CPEC</td>
<td>constituent of potential ecological concern</td>
</tr>
<tr>
<td>CSM</td>
<td>Conceptual Site Model</td>
</tr>
<tr>
<td>DQRR</td>
<td>data quality review reports</td>
</tr>
<tr>
<td>DQO</td>
<td>data quality objective</td>
</tr>
<tr>
<td>DEQ</td>
<td>Oregon Department of Environmental Quality</td>
</tr>
<tr>
<td>EDD</td>
<td>electronic data deliverable</td>
</tr>
<tr>
<td>EPA</td>
<td>United States Environmental Protection Agency</td>
</tr>
<tr>
<td>EPH</td>
<td>extractable petroleum hydrocarbon</td>
</tr>
<tr>
<td>ERA</td>
<td>ecological risk assessment</td>
</tr>
<tr>
<td>°F</td>
<td>degrees Fahrenheit</td>
</tr>
<tr>
<td>ft</td>
<td>foot</td>
</tr>
<tr>
<td>FGA</td>
<td>fine grained alluvium</td>
</tr>
<tr>
<td>FM</td>
<td>Field Manager</td>
</tr>
<tr>
<td>Ft/day</td>
<td>foot per day</td>
</tr>
<tr>
<td>HASP</td>
<td>Health and Safety Plan</td>
</tr>
<tr>
<td>HC</td>
<td>hydraulic control</td>
</tr>
<tr>
<td>IDW</td>
<td>investigative derived waste</td>
</tr>
<tr>
<td>in/yr</td>
<td>inches per year</td>
</tr>
<tr>
<td>IRM</td>
<td>Interim Remedial Measure</td>
</tr>
<tr>
<td>LCC</td>
<td>limited liability company</td>
</tr>
<tr>
<td>LCS</td>
<td>laboratory control samples</td>
</tr>
<tr>
<td>LP</td>
<td>limited partnership</td>
</tr>
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USGS  U.S. Geological Survey
VOCs  volatile organic compounds
VPH  volatile petroleum hydrocarbon
1.0 INTRODUCTION

AECOM, on behalf of the Atlantic Richfield Company (ARC) (a British Petroleum [BP]-affiliated company), has prepared this Sampling and Analysis Plan (SAP) to describe the procedures for the collection of annual groundwater monitoring samples at the BP Terminal 22T facility (Terminal 22T), located in Portland, Oregon (Figure 1-1). Updates to the semi-annual groundwater conducted at Terminal 22T are reflected in this SAP:

1) Reduce semi-annual sampling schedule to annually, conducted during the first quarter when groundwater volume is optimal.

2) Current distribution of constituents of potential concern (COPCs) and constituents of potential ecological concern (CPECs) associated with historic TPH releases.


4) Source control measures (SCMs).

1.1 WORK PLAN ORGANIZATION

The SAP is organized as follows:

- Section 1 provides introduction and background information
- Section 2 describes the conceptual site model.
- Section 3 describes the groundwater sampling program.
- Section 4 describes the quality assurance and quality control (QA/QC) plan including data quality objectives (DQOs), data management, and data validation to implement the SAP.
- Section 5 describes overall management strategy for implementation of the groundwater monitoring program.

1.2 PROJECT BACKGROUND

The following section summarizes the current conditions at Terminal 22T, facility operations, sources of contamination, and completed source control measures.

1.2.1 Site Description

Terminal 22T is a bulk petroleum product storage and transfer facility located at 9930 NW St. Helens Road (Oregon Highway 30) in Portland, Oregon (Figure 1-2). The facility has been in operation since approximately 1928. Terminal 22T is bordered to the east by the Willamette River, to the west by NW St. Helens Road, to the north by an unoccupied property owned by the LPA, and to the south by a bulk terminal owned and operated by Shore Terminals limited liability
company, a subsidiary of NuStar Energy limited partnership. The LPA property is proposed for redevelopment as a natural resources restoration area for the Portland Harbor Superfund Site.

1.2.2 Site Contaminants

Historical releases of total petroleum hydrocarbons (TPH), primarily consisting of diesel product, have occurred at Terminal 22T, which have resulted in contaminated subsurface soil and groundwater. Liquid-phase hydrocarbons (LPH) and dissolved-phase constituents have been reported in soil and groundwater at Terminal 22T, and the southern edge of the adjacent LPA property during previous environmental investigations. Constituents of potential concern (COPCs) and constituents of potential ecological concern (CPECs) associated with historic TPH releases fall into the following three categories (URS, 2012):

1) TPH: TPH as gasoline (TPH-Gx) and TPH as diesel (TPH-Dx)
2) Polycyclic aromatic hydrocarbons (PAHs): benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, indeno(1,2,3-cd)pyrene, and dibeno(a,h,) anthracene
3) Metals: arsenic and barium

1.2.3 Groundwater Source Control Measure

Currently, two groundwater SCMs implemented at Terminal 22T have effectively eliminated LPH migration to the Willamette River and reduced the transport of constituents in both the shallow and deep groundwater zones from Terminal 22T to the Willamette River so the constituents do not present a risk to the Willamette River (URS, 2013). A summary of each groundwater SCM is provided below:

1) Sheet Pile Seawall: A 900-foot long sheet pile seawall installed into the fine-grained alluvium layer prevents shallow zone migration of LPH and dissolved-phase constituents to the Willamette River.
2) Hydraulic SCM: A pump and treat system was installed from 2005 to 2008 and includes a series of hydraulic control (HC-1 and HC-3) and extraction wells (SC-1 through SC-11 and SC-13 through SC-23, and CP-2 and HC-2). The hydraulic control wells create a cone of depression and reverse the groundwater gradient from the seawall towards the center of the site. The extraction wells contain total fluids pumps (TFPs) that induce shallow, local cone of depression to allow the capture of LPH and groundwater along the seawall. In addition, skimmers are installed in monitoring wells HC-1, HC-3, RW-02, MW-01, MW-08, MW-13 and LPMW-01 and a spill buster is installed in monitoring well MW-11. Groundwater and LPH are extracted from the subsurface, primarily from the center of Terminal 22T and along the seawall. Extracted groundwater and LPH are processed through an above ground treatment system, which separates LPH from
groundwater and treats groundwater prior to discharge through the NPDES outfall to the Willamette River.

1.2.4 Groundwater Chemistry Trends

Groundwater chemistry trends of site-specific COPCs and CPECs identified for groundwater and Willamette River surface water and sediment receptors include the following:

1) TPH-Gx and TPH-Dx: The current extent of LPH at Terminal 22T is stable, as demonstrated by comparing historical LPH extent maps to recent LPH extent maps (URS, 2013). In addition, the extent of dissolved TPH, as TPH-Gx and TPH-Dx, has not changed significantly, as demonstrated by comparing historical TPH-Gx and TPH-Dx concentration to recent TPH-Gx and TPH-Dx concentrations (URS, 2013). The results of 2014 groundwater monitoring activities indicate that TPH-Gx and TPH-Dx are present at concentrations exceeding applicable human health and ecological screening levels in both shallow and deep wells (AECOM, 2015).

2) PAHs: The results of 2014 groundwater monitoring activities indicate that PAHs (benzo(a)anthracene, benzo(a)pyrene, benzo(b)fluoranthene, benzo(k)fluoranthene, chrysene, and indeno(1,2,3-cd)pyrene, dibenzo(a,h,) anthracene) are present at concentrations exceeding applicable human health SLVs in shallow groundwater and in deep groundwater at one well location (MD-02) (AECOM, 2015).

3) Metals: The results of the 2014 groundwater monitoring activities indicate total arsenic is present in shallow and deep groundwater at concentrations exceeding the human health SLV. Total barium is present in shallow and deep groundwater at concentrations exceeding the ecological SLV (AECOM, 2015).

1.2.5 Groundwater Modeling Results

A three dimensional numerical groundwater fate and transport model was completed in 2013 (URS, 2013) to evaluate COPCs and CPECs associated with historic TPH releases (URS, 2013). The numerical groundwater flow model indicates the SCM groundwater extraction wells provide an adequate capture zone throughout most of Terminal 22T. However, the 30-year model indicates the potential of CPEC TPH carbon chain fraction (aliphatic C6-C8) and CPEC (aromatic C10-C12) around the north end of the seawall to migrate to the Willamette river at concentrations greater than the ecological screening level values (SLVs) for river sediment and pore water, and river sediment, respectively. The fate and transport model results indicate COPC/CPECs do not have the potential to increase sediment concentrations of COPC/CPECs above human health screening criteria.
1.2.6 Interim Remedial Measure

An interim remedial measure (IRM) was implemented between April and May 2015 to prevent potential migration of COPCs/CPECs groundwater around the north end of the sea wall and to remediate LPH and dissolved-phase COPCs/CPECs on the LPA property. The primary components to the IRM include:

- Expanding the existing hydraulic SCM system by adding four additional pumping wells near the northern Terminal 22T property boundary; and
- Conducting remedial action using trap and treat remedial technology at the adjacent LPA property.

Quarterly groundwater monitoring of the LPA monitoring wells will be conducted under a separate groundwater monitoring program in accordance with the IRM Work Plan (URS, 2014) to evaluate the effectiveness of the IRM.
2.0 CONCEPTUAL SITE MODEL

A summary of Conceptual Site Model (CSM) at Terminal 22T is presented in the following section.

2.1 TOPOGRAPHIC CONDITIONS

Terminal 22T is located within the southwestern portion of the Portland Basin (Figure 1-1). Elevation at Terminal 22T ranges from 40 feet City of Portland vertical datum (CPD) near NW St. Helens Road and slopes gently downwards to the east towards the Willamette River, with an elevation of approximately 32 feet CPD along the seawall. The Portland Hills are located west and upgradient of Terminal 22T with maximum elevations of approximately 1,000 feet CPD. The Portland Hills contribute to weather patterns, and provide groundwater recharge to Terminal 22T through surface infiltration of rainwater.

The shoreline surface past the seawall is at an elevation of approximately 5 feet CPD and slopes to the east gradually over a distance of approximately 40 feet and then drops sharply to -10 feet CPD. The river channel is deepest approximately 400 feet from the shoreline, at an elevation of -42 feet CPD. When the Willamette River stage exceeds 16 feet CPD, the surface water covers the entire shoreline zone and when the Willamette River stage is low (below 5 feet CPD), the shoreline zone is approximately 50 feet wide and is sub-aerially exposed to the atmosphere.

2.2 REGIONAL CLIMATE AND HYDROLOGY

Portland’s climate consists of mild, wet winters with an average high temperature of 45 degrees Fahrenheit (°F) and an average low temperature of 34 °F, and relatively dry, warm summers, with an average high temperature of almost 80 °F and an average low of 57 °F. During the winter Portland can average over five inches of rain per month for several months in a row, while averaging less than an inch of rain per month during the summer. The long-term annual average rainfall ranges from 39 inches per year (in/yr) at the Yeon Avenue Rain Gauge¹ to 45 in/yr in the Tualatin Mountains² west of the Site.

2.2.1 Willamette River

The Willamette River flows northward, and is approximately 1,200 feet wide near Terminal 22T. On average, the daily Willamette River elevation ranges from less than 5 feet to near 20 feet CPD at the U.S. Geological Survey (USGS) Morrison Bridge gauge, which is located at

¹ Yeon Avenue rainfall data: [http://or.water.usgs.gov/non-usgs/bes/raingage_info/clickmap.html](http://or.water.usgs.gov/non-usgs/bes/raingage_info/clickmap.html)

Willamette River Mile (RM) 12.8, approximately 7.8 miles upstream of Terminal 22T. The variation of daily Willamette River elevations is primarily the result of seasonal variation in rainfall, but is also influenced by a 6-hour tidal cycle. The tidal fluctuation within the river varies from approximately 0.4 feet to approximately 2.5 feet.

2.3 GEOLOGY

The geology at Terminal 22T generally consists of bedrock overlain by layers of sandy alluvium (SA), FGA, and sandy fill with a paleochannel cutting across part of the site. The stream deposits are further described below in Section 2.3.2. Additional details for each major stratigraphic unit are provided below.

2.3.1 Sandy Fill

The sandy fill unit is a combination of sand, clayey sand, sandy gravel, silt, clayey silt, sandy silt, and woody debris (wood chips, fibers and planks). The woody debris is present in localized areas, predominantly along the seawall at the eastern boundary of Terminal 22T and at the LPA property, and occurs most often at the base of the sandy fill unit. The properties of the sandy fill unit vary widely across the site. The center of Terminal 22T is characterized by areas of higher permeability fill material.

The sandy fill unit thickens toward the river and is locally absent in the northwest portion Terminal 22T. The unit thickness ranges from 3 feet near the loading rack to 30 feet near the river. The fill is in direct contact with the underlying FGA except for localized areas where they are underlain by the stream deposits.

2.3.2 Stream Deposits

Stream deposits are locally present between the sandy fill. It is distinguishable from overlying and underlying units by its sand and silty sand texture, interbeds of silt and clayey silt, and presence of rootlets and bioturbation. The deposits range from 2 to 10 feet thick, up to 220 feet wide, and cross Terminal 22T from the center of the south tank farm to the center of the site along the riverfront. The hydraulic conductivity of the stream deposits is similar to the overlying sandy fill material and distinctively higher than the underlying FGA unit.

2.3.3 Fine Grained Alluvial Deposits

The FGA consists of silt and lean clay that locally grades to silty sand or includes silty sand interbeds. The unit is generally finer-grained than the overlying sandy fill and stream deposits

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3 The City of Portland Vertical Datum is 2.1 feet above North American Vertical Datum (NAVD) of 1988
4 http://waterdata.usgs.gov
and the underlying SA unit. The FGA thickness ranges from 15-20 feet thick along the river to 9-17 feet thick along the western edge of Terminal 22T, and the thickness is relatively uniform parallel to the river. The FGA is contiguous across Terminal 22T, except where it is locally incised by the stream deposits. The unit is shallow in the area near the truck loading rack. In the northwest portion of Terminal 22T the FGA is present within approximately 1 foot of the ground surface where the sandy fill is locally absent.

2.3.4 Sandy Alluvial Deposits

The SA is a contiguous unit of fine sand with interbeds of silty sand and silt lying between the FGA and the basalt bedrock. Like the FGA, the SA dips towards the river. The thickness and physical characteristics of the unit are relatively uniform across Terminal 22T.

2.3.5 Bedrock

Basalt bedrock underlies the SA at depths ranging from approximately 40 feet along the western edge of the Site to approximately 70 feet along the riverfront. The top of bedrock dips toward the river.

2.4 HYDROGEOLOGY

Eight distinct aquifer and confining units characterize regional hydrogeology in the Portland Basin (Swanson et al., 1993). The unit nearest Terminal 22T is a shallow, unconfined aquifer receiving recharge from surface infiltration including precipitation, rivers and streams, and human systems. Throughout the basin this aquifer recharges in upland areas and mainly discharges to the major rivers including the Willamette, Columbia, Lewis, and Clackamas.

2.4.1 Hydrogeological Conceptual Site Model

Two main groundwater zones have been identified underlying Terminal 22T and the LPA property, referred to as “shallow groundwater” and “deep groundwater.” The sandy fill and stream deposits together comprise the “shallow” groundwater zone and the SA comprises the “deep” groundwater zone as described below. Figure 2-1 shows the current CSM.

As described in the Final Hydraulic Source Control Implementation (SCI) Report (URS, 2006) and the Revetment Source Control Measure Report (URS, 2007), the FGA is observed between the shallow fill/stream deposits and the deeper sandy alluvial deposit. Where the FGA is continuous, it is believed to inhibit vertical groundwater migration between the shallow and deep groundwater zones. Therefore, the CSM includes groundwater in two distinct zones:

1. **Shallow zone** – unconfined groundwater system within the sandy fill and stream deposits, which are observed to depths of -5 feet CPD adjacent to the river and +10 feet CPD in the western portion of Terminal 22T. The fill and stream deposits, have higher
permeability and between which there is no hydrologic barrier. Shallow groundwater flow is controlled by groundwater extraction wells and the seawall on the eastern edge of Terminal 22T. Pumping and slug tests performed during 2008 and 2009 have shown hydraulic conductivities ranging from less than 1 foot per day (ft/day) to approximately 14 ft/day in shallow groundwater (URS, 2011).

2. **Deep zone** – within the SA which is below the FGA unit and on top of the basalt bedrock. The SA is observed to depths of -40 feet CPD near the river, but is much shallower near the western edge of Terminal 22T, and is referred to as the “deep groundwater zone”. Deep groundwater is hydraulically connected to the Willamette River. The deep groundwater zone hydraulic properties were estimated using pumping and slug tests conducted in 2008 and 2009. The pumping tests showed hydraulic conductivities ranging from less than a 1 ft/day to almost 12 ft/day. Slug tests were limited in range and provided conductivity values of 0.01 ft/day to approximately 2.5 ft/day.

Previous investigations indicate the FGA aquitard has a low hydraulic conductivity of 1 ft/day or less (URS, 2004). The FGA unit is continuous along the riverfront where it provides an effective hydrologic barrier between the two groundwater zones. The seawall is terminated into the FGA confining unit, providing a barrier for groundwater flow from the shallow zone to the Willamette River.

There are both upward and downward vertical hydraulic gradients across Terminal 22T, varying in direction and magnitude depending on Willamette River elevation, groundwater elevation, and groundwater extraction rates. There is a consistently downward hydraulic gradient along the east and central portions of Terminal 22T; upward hydraulic gradients occur mostly west of the truck loading rack, and in the northwest portion of Terminal 22T. An upward hydraulic gradient is induced in the center of Terminal 22T by the groundwater extraction wells.

Groundwater flow is influenced by precipitation, seasonal river elevation changes, daily tidal variations, and operation of the hydraulic SCM system. During winter high-water conditions, groundwater elevations rise and the lateral extent of the LPH plume increases (and thickness decreases). In contrast, during low-water conditions in the late summer, groundwater elevations are low and the lateral extent of the LPH plume is smaller, but the vertical extent is thicker (URS, 2006).

The hydraulic SCM system extracts groundwater from both the shallow and deep groundwater zones. Two hydraulic control wells, HC-1 and HC-3, are screened across both of the water-bearing zones. In addition, shallow pumping wells adjacent to the seawall extract water from the shallow groundwater zone.
3.0 GROUNDWATER SAMPLING PROGRAM

This section describes the procedures for the collection of performance groundwater samples including: laboratory analyses, field sampling procedures, sample locations, number of samples, and QA/QC samples. Section 5.0 describes the quality control and quality assurance (QA/QC) program in detail.

Detailed sampling procedures are provided in the Standard Operating Procedures (SOPs) in Appendix A. The SOPs are listed below.

1) SOP 1. Daily Field Notes and Maintenance
2) SOP 2. Sample Handling, Labeling, Packaging, and Shipping
3) SOP 3. Sample Control, Documentation, and Tracking
4) SOP 4. Groundwater Level Measurements
5) SOP 5. Field and Laboratory Quality Control Sample Collection
6) SOP 6. Groundwater Sampling

3.1 GROUNDWATER ELEVATION AND LPH DEPTH MEASUREMENT

Groundwater elevations and the presence of LPH will be measured quarterly at 88 monitoring wells at Terminal 22T and 8 monitoring wells at the LPA property, with results recorded on Well Data Collection Forms included Appendix B. Groundwater elevation and LPH thickness will be measured quarterly in accordance with SOP 4, using an electronic Solinist® water-product interface probe at all wells except the continuous multichannel tubing (CMT) wells. The small diameter of the CMT well ports require a small diameter electronic water level indicator to be used and only groundwater elevation will be measured. The depth to groundwater will be measured to the nearest 0.01 foot from a surveyed notch or permanent mark at the top of the polyvinyl chloride (PVC) well casing. Non-dedicated sampling equipment will be decontaminated as described in SOP 4 before sampling and between sampling locations. The depth to groundwater measurements, monitoring date and time, river stage measurements, and type of equipment installed in the well (i.e. pump or transducer, if applicable) will be recorded on the Well Data Collection Forms in Appendix B.

3.2 GROUNDWATER SAMPLE COLLECTION

Groundwater samples will be collected annually during first quarter when groundwater volume is optimal, at 29 monitoring wells identified in Table 3-1, with monitoring well locations shown in Figure 3-1. Standard groundwater samples will be collected in accordance with SOP 6 using a low flow groundwater sampling methodology using a peristaltic pump and dedicated polyethylene tubing. The field personnel will document groundwater sampling at each monitoring well, including the groundwater sample ID and time, on the Monitoring Well Sampling Field Log included in Appendix B. Groundwater sample analyses are listed in Table 3-1 with...
QA/QC sampling requirements. The analytical methods, specific container types, preservation requirements, and hold times for each analysis are listed in Table 3-2.

3.2.1 Laboratory Analysis

Groundwater samples collected from the wells identified in Table 3-1 will be submitted to an ARC accredited environmental laboratory for the following analyses:

- TPH-Gx by NWTPH-Gx,
- TPH-Dx by NWTPH-Dx with silica gel cleanup,
- Benzene, toluene, ethylbenzene, and xylenes (BTEX) and methyle ter-butyl ether (MTBE) by EPA Method 8260B,
- PAHs by EPA Method 8270-SIM,
- Total Resource Conservation and Recovery Act (RCRA) 8 Metals by EPA Methods 6010B/6020.

3.2.2 QA/QC Sampling

The following QA/QC samples will be collected during the groundwater sampling events:

- Field duplicates will be collected during each sampling event at a rate of approximately 5% of the primary samples (e.g., 1 per 20 samples) in accordance with the procedures described in Section 5.4.
- One Matrix Spike/Matrix Spike Duplicate (MS/MSD) sample will be collected at a rate of approximately 5% of the primary samples (e.g., 1 per each 20 samples) during each sampling event, as described in Table 3-2. The chain-of-custody will indicate which sample will be designated for MS/MSD analysis.
- One trip blank will be placed in each cooler containing sample containers for BTEX and MTBE analysis.
- One temperature blank will be placed into each cooler during the sampling.

3.2.3 Sample Naming

The sample IDs for the groundwater samples will be labeled in the following manner:

- The first part of the sample name will be a six digit number indicating the date the sample is collected in format Year (XX) Month (XX) Date (XX) (e.g. September 15, 2015):
  - 150915
- The second part of the sample name will be the designated well ID (e.g. LPWM-11):
  - 150915-LPMW11
- The third part will be the sample depth (e.g. 30 feet):
  - 150915-LPWM11-30
The fourth part will be a description of the sampling matrix (i.e. groundwater):
- 150915-LPWM11-30-GW

### 3.3 SAMPLE HANDLING AND CUSTODY

This section describes the sample handling procedures from sample collection through sample disposal. The purpose of these procedures is to ensure that the quality of samples is maintained during collection, transportation, storage, and analysis. Additional details are provided in SOPs 2 and 3.

A required part of any sampling and analytical program is the integrity of the sample, from sample collection to data reporting. This includes the ability to trace the possession and handling of samples from the time of collection, through analysis, and final disposition. The essential components of this chain are summarized below.

#### 3.3.1 Sample Containers, Preservation, and Holding Times

Samples will be placed directly into the appropriate sample container for each analytical method. Sample container types, preservation, and holding times are summarized on Table 3-2.

The field sampling personnel are responsible for the care and custody of samples until they are delivered (or shipped) to the laboratory custodian. The sampler will protect the sample from positive or negative contamination by decontaminating sampling tools between each sample site (as applicable) and by protecting the samples from contamination from hand contact.

The samples will be securely packed in coolers with ice to maintain samples at 4 degrees Celsius (°C) during transport to the laboratory. All samples will be accompanied by chain-of-custody forms. Chain-of-custody records will be maintained by AECOM to document and verify sample transfer to the laboratory. A temperature blank, consisting of a small container of water labeled “temperature blank,” will be shipped with each cooler. This will facilitate the measurement of the cooler temperature upon lab receipt. Processed samples will be shipped on ice in coolers via either courier or shipping service company with adequate ice to keep samples cool for at least two days.

#### 3.3.2 Sample Custody

After sample collection, samples will be kept in the custody of field personnel until formally transferred to the laboratory or storage area. For the purposes of this work, custody will be defined as follows:

- Samples are in plain view of the field personnel; or
- Samples are stored inside an appropriate container that is in plain view of the field personnel; or
• Samples are stored inside any locked space such as a cooler, locker, car, truck, trailer, or office to which field personnel have the only immediately available key(s) or lock combination.

3.3.2.1 Custody Records

Custody records, defined as formal chain-of-custody forms, will be maintained for all samples. The information on the chain-of-custody form shall contain, at a minimum, the following:

• Project name,
• Sample identification number,
• Date and time of sample collection,
• Sample location identification and/or description,
• Sample matrix type,
• Sample preservation,
• Signatures of sample handlers,
• Type of analyses requested,
• Number of containers submitted for each sample,
• Method of shipment,
• Signatures indicating relinquishment and acceptance of samples including date and time of sample transfer, and
• Contact information and name of person to who results should be reported.

The field manager (FM) will be responsible for sample tracking and chain-of-custody procedures in the field. The FM, or his/her designee, will fill out the chain-of-custody forms prior to transferring samples into shipping coolers. All information on the chain-of-custody forms will be cross-checked against field forms and sample labels prior to sample transfer.

Custody seals will be affixed to the shipping containers. The custody seals will contain, at a minimum the signature of the person responsible for the samples and the date when the custody seal was applied.

3.3.2.2 Laboratory Custody Procedures

A sample custodian at the laboratory will accept custody of the shipped samples from the carrier and enter the preliminary information about the samples into a sample receipt log, including the initial and/or name of the person or company delivering the samples and the status of the custody seals on the coolers (i.e., broken versus unbroken). The custodian responsible for sample log-in will follow the laboratory’s SOP for opening the coolers, checking cooler temperature, checking the contents, and verifying that the information on the chain-of-custody forms agrees with the samples received.

A custodian at the laboratory will verify that the containers are intact and verify that the documentation accompanying the samples corresponds to the actual contents. Any anomalies,
such as broken containers, elevated temperatures, and missing labels, will also be documented by the laboratory custodian. The laboratory will retain sample identification tags, data sheets, original instrument output records, and logbooks, as part of the final file. If samples are broken or otherwise can't be analyzed, the laboratory will contact AECOM as soon as possible so replacement samples can be collected, if necessary.

3.3.3 Sample Disposal
After the analyses have been completed, the samples will be disposed of at a licensed hazardous waste facility according to RCRA regulations.

3.4 DECONTAMINATION PROCEDURES
Potential sources of contamination in the field include sampling equipment, vehicles, and dust. Sample handling will be minimized and sources of contamination will be carefully avoided. Samplers will wear disposable powder-free nitrile gloves during all sample handling procedures.

3.5 WASTE MANAGEMENT
Investigation derived waste (IDW) generated during groundwater monitoring activities will include: decontamination fluids, purge water, and miscellaneous wastes (gloves, sample tubing, paper towels, garbage bags etc.). Decontamination and purge water will be added to Terminal 22T on-site water treatment system. Miscellaneous wastes will be disposed of at an approved solid waste disposal facility.
4.0 QUALITY ASSURANCE AND QUALITY CONTROL PLAN

This section describes components of the QA/QC program including procedures, sampling requirements, documentation, and QA/QC protocols necessary to achieve the data quality objectives (DQOs).

4.1 CHEMICAL ANALYSES AND PERFORMANCE CRITERIA

Analyses will be performed at a ARC accredited lab. The analytical methods are based on the most current analytical protocols as cited. QC performance criteria should comply with test methods as represented in SW-846 Manual, Test Methods for Evaluating Solid Waste, Physical/Chemical Methods (EPA, 2007) or other cited method and with laboratory-generated performance criteria. Samples will be analyzed according to the monitoring plan summarized in Table 3-1.

4.2 DATA QUALITY OBJECTIVES

DQOs are qualitative and/or quantitative statements of the precision (a measure of the random error), accuracy (a measure of systematic error), representativeness, completeness, and comparability necessary for the data to meet the objectives of the project. During plan implementation, field as well as laboratory data will be generated. The quality of the field data will be evaluated based on successful calibration of each instrument supplying the data and the stated accuracy and precision by the manufacturer. The quality of laboratory data will be evaluated based on the relative precision, accuracy, representativeness, completeness, and comparability of the data generated by each type of analysis. These terms are defined in the following subsections.

4.2.1 Precision

Precision can be measured in a variety of ways. For chemical analysis of environmental samples, precision is commonly determined from duplicate sample analyses; thus, precision is usually expressed as relative percent difference (RPD). In accordance with the method criteria, samples analyzed shall include laboratory duplicates, matrix duplicates and/or matrix spike duplicates to evaluate precision in this manner. In addition, field duplicate precision will be evaluated when applicable. Precision determined by RPD shall be calculated as follows:

\[
\%\text{RPD}_i = \frac{2|O_i - D_i|}{O_i + D_i} \times 100\%
\]

where:

\[
\%\text{RPD}_i = \text{Relative percent difference for compound } i
\]

\[
O_i = \text{Value of compound } i \text{ in original sample}
\]
\[ D_i = \text{Value of compound } i \text{ in duplicate sample} \]

The resultant RPD will be compared to laboratory-specific acceptance control limits. The RPD will be reviewed during data quality review, and the reviewer will note any deviations from the laboratory control limits and comment on any effects on the data.

### 4.2.2 Accuracy

Analytical accuracy may be assessed through the use of known and unknown QC samples and spiked samples. Accuracy is presented as percent recovery. Accuracy will be determined from MS/MSD and laboratory control samples (LCS), as well as from surrogate compounds added to organic fractions. Accuracy is calculated as follows:

\[
\%R_i = \left( \frac{Y_i}{X_i} \right) \times 100\%
\]

where:

- \( \%R_i \) = percent recovery for compound \( i \)
- \( Y_i \) = measured analyte concentration in sample \( i \)
- \( X_i \) = known analyte concentration in sample \( i \)

The MS/MSD, and LCS resultant percent recoveries will be compared to laboratory control limits. Percent recoveries will be reviewed during data quality review, and the reviewer will note any deviations from the specified control limits and comment on any effects on the data.

### 4.2.3 Representativeness

Representativeness is a qualitative parameter that expresses the degree to which sample data accurately and precisely represent a characteristic of a population, parameter variations at a sampling point, or an environmental condition. Representativeness of the environmental conditions at the time of sampling is achieved by selecting sampling locations, methods, and times so that the data describe the site conditions that the project seeks to evaluate. Representative samples will also be ensured through following proper protocols for sample handling (storage, preservation, packaging, custody, and transportation), sample documentation, and laboratory sample handling and documentation procedures.

### 4.2.4 Completeness

Completeness for usable data is defined as the percentage of usable data out of the total amount of planned data. Completeness will be calculated as follows:

\[
\%C = \frac{A}{I} \times 100\%
\]

where:
%C = Percent completeness (analytical)
A = Measurements that are judged to be usable (based on project-specific requirements)
I = Intended number of measurements

Invalid data (i.e., data qualified as “R,” rejected) will be identified during the data quality review.

4.2.5 Comparability

Comparability is a qualitative parameter that expresses the confidence with which data from one study can be compared with data from another. This goal will be achieved by using standard techniques to collect and analyze representative samples and by reporting analytical results in appropriate units. Comparability will be evaluated during the data quality review.

4.3 ANALYTICAL METHOD LIMITS

The laboratory methods and method reporting limits should ensure sufficient sensitivity to meet project objectives. The method detection limit (MDL) and method reporting limit (MRL) are defined below. All analytical results will be reported to the MDL value; results between the MRL and MDL will be reported as estimated.

4.3.1 Method Detection Limit

The MDL is the lowest concentration of a chemical that can be “seen” above the normal, random noise of an analytical instrument or method with a 99% confidence. Detection limits are chemical-specific and instrument-specific, and are determined by statistical treatment of multiple analyses in which the ratio of the lowest amount observed to the electronic noise level is determined. A MDL also considers sample matrix, preparation steps, and reagents used for a sample in a specific analytical method. Note that, on any given day in any given sample, the calculated limit may or may not be attainable.

4.3.2 Method Reporting Limit

A MRL represents the minimum concentration that can be reported as a quantitated value for a target analyte in a sample. This defined concentration can be no lower than the concentration of the lowest calibration standard for the analyte, and can only be used if acceptable quality control criteria for the analyte concentration are met. It may be based on project-specific concentrations of concern, regulatory action levels, or sensitivity capability of method and instrument. The MRLs are adjusted based on the sample matrix and any necessary sample dilutions.
4.4 QUALITY CONTROL PROCEDURES

The overall QC objectives for field sampling and laboratory analysis are to produce data of known and appropriate quality to support the project objectives. Appropriate procedures and QC checks will be used so that known and acceptable levels of precision, accuracy, representativeness, completeness, comparability, sensitivity and contract compliance are maintained as applicable for each data set.

Field QC and laboratory QC samples will be employed to evaluate data quality. QC samples are controlled samples introduced into the analysis stream whose results are used to review data quality and to calculate the accuracy and precision of the chemical analysis program. The purpose of each type of QC sample, collection and analysis frequency, and evaluation criteria are described in this section. Laboratory QC samples, as described in the referenced methods, will be followed.

The quality of field and laboratory measurements will generally be determined by the QC requirements and quality criteria described in analytical methods. All QC measurements and data assessment for this project will be conducted on samples from and within batches of samples from this project alone when possible.

QC checks for sample collection will be accomplished by a combination of chain-of-custody protocols, field QC samples, and laboratory QA as described in the sampling or analytical methods. The QC measures may include the following: method blanks; matrix, surrogate, and laboratory control spikes, and laboratory duplicate samples. The laboratory will notify the AECOM QA Manager of any QC exceedances.

4.4.1 Field QC Samples

Field QC samples are collected to evaluate the quality of the field sampling program. Specifically, field duplicate samples are collected to monitor the variability associated with sample collection techniques. Field QC samples will be selected by the sampling team and designated on the Monitoring Well Sampling Field Log (Appendix B).

Field duplicates will be collected at a rate of approximately 5% of the primary samples (e.g., 1 per 20 samples). Based on the number of primary samples (29 samples per semiannual event), field duplicate samples will be collected as follows:

- During collection of the sample, collect twice the volume as typically collected.
- Place the sample in double the typically required sample containers.
- Label each as a unique sample and submit both samples for the same analyses.
4.4.2 Laboratory QC Samples

Laboratory QC checks are accomplished by analyzing initial and continuing calibration samples, method blanks, surrogate spikes, LCS(s), and laboratory duplicate samples. Not all of these QC samples will be required for all methods.

Method blanks are used to check for laboratory contamination and instrument bias. Laboratory method blanks will be analyzed at a minimum of one per analytical batch. Analytical results for each sample shall be clearly associated with a particular method blank. In order to evaluate low level determinations of target compounds in samples, the laboratory will report any detected concentration found in method blanks that exceed laboratory-derived control limits.

LCSs are used to monitor the laboratory’s day-to-day performance of routine analytical methods, independent of matrix effects. The LCS is prepared by spiking deionized water with standard solutions prepared independently of those used in establishing instrument calibration. The LCS are extracted and analyzed with each batch of samples. Results are compared on a per-batch basis to established control limits and are used to evaluate laboratory performance for precision and accuracy. LCS may also be used to identify any background interference or contamination of the analytical system that may lead to the reporting of elevated concentration levels or false positive measurements.

MS samples are used to assess sample matrix interferences and analytical errors, as well as to measure the accuracy of the analysis. Known concentrations of analytes are added to environmental samples as the MS/MSD samples, which are processed through the entire analytical procedure and the recovery of the analytes is calculated. Results are expressed as percent recovery of the known spiked amount. MS/MSD samples will be analyzed at a minimum of one per analytical batch, in accordance with method requirements. The MS/MSD samples will be analyzed for the same parameters as the associated field samples in the same analytical batch.

MS samples will be identified on the chain-of-custody form, and additional sample volumes will be provided to the laboratory. MS analyses not meeting laboratory-derived QC criteria will be further evaluated through additional cleanup or one reanalysis.

Precision of the analytical system is evaluated by using laboratory duplicates. Laboratory duplicates are two portions of a single homogeneous sample analyzed for the same parameter. Laboratory duplicates with be analyzed at a minimum of one per analytical batch, when applicable.

4.5 DATA MANAGEMENT

The approach to data management for this project will ensure that analytical data maintain their integrity through the use of appropriate documentation procedures.
4.5.1 Laboratory Data Reduction

Laboratory analytical data are first generated in raw form at the instrument. These data may be in either graphic form or printed in tabular form. Specific data reduction, generation procedures, and calculations are found in each of the methods, as well as within the laboratory quality assurance project plan. Analytical results must be reported consistently. Data reduction will be performed by individuals (i.e., laboratory and QA Manager) experienced with a particular analysis and knowledgeable of project QA/QC requirements.

4.5.2 Laboratory Data Deliverables

Deliverables by the contract laboratory shall be in Tier II data package format. The laboratory data reports will consist of data packages that will contain documentation and all raw data to allow independent data verification and review of analytical results from laboratory bench sheets, instrument raw data outputs, chromatograms, and mass spectra. Each laboratory data report will include the following:

- Case narrative identifying the laboratory analytical batch number. The Laboratory QA Manager or their designee must sign the narrative.
- Matrix and number of samples included.
- Analyses performed and analytical methods used.
- Description of any problems or exceedances of QC criteria and corrective action taken.
- Copy of chain-of-custody records for all samples included in the analytical batch.
- Tabulated sample analytical results with units, data qualifiers, percent solids, sample weight or volume, dilution factor, laboratory batch and sample number, field sample number, and dates sampled, received, extracted, and analyzed all clearly specified. Surrogate percent recoveries will be included for organic analyses.
- MRLS and MDLs will be reported for each analyte. Those analytes which have concentrations above the MDL but below the MRL will be appropriately flagged by the laboratory.
- All calibration, QC, and sample raw data including bench sheets, preparation logs, chromatograms, mass spectra, mass spectrometer tuning results, quantitation reports, and other instrument output data as applicable to analytical method.
- Blank summary results indicating samples associated with each blank.
- Matrix spike result summaries with calculated percent recovery.
- Laboratory control sample results, when applicable, with calculated percent recovery.

In addition to the Tier II data package report, the laboratories will provide the data in an electronic data deliverable (EDD) which mirrors the written laboratory report.
4.5.3 Laboratory Turnaround Time
The required turnaround time for data deliverables by the contract laboratory shall be the laboratories standard turnaround time (generally 10 to 14 working days) from the time of sample receipt at the contract laboratory.

4.5.4 Electronic Data Management
An electronic data management system will be used to track, access, and report the following:

- Sample location (northing and easting), using coordinate systems compatible with earlier field work.
- Sample collection information including sample number, matrix, type of sample (primary, MS, duplicate), date of collection, and sampler.
- Analytical results including concentration, units, qualifiers and analytical method.

Laboratory EDDs will be directly loaded into the data management system by the database administrator, thereby avoiding hand-entry errors. The accuracy between the analytical results reported in the portable document format (pdf) and the EDD deliverables are checked by the database administrator at a frequency of 20% or greater. If discrepancies are encountered between the laboratory deliverables, the laboratory is notified and a 100% check is performed on that data set. Corrective action is taken, which typically includes the database administrator removing the effected EDD and reloading the laboratory corrected EDD into the data management system.

Changes in analytical results or qualifiers due to the QA/QC review as presented in the Data quality review reports (DQRR) are incorporated into the project data management system. The accuracy of these database modifications is checked by producing reports (or tables) from the data management system which are crosschecked against the DQRR.

Within the data management system, the database administrator records:

- Date of EDD upload,
- Verification of pdf to EDD crosscheck and frequency,
- Date of qualifiers added as a result of QA/QC review, and
- Any other pertinent project notes (i.e. sample description).

4.6 DATA VALIDITY AND USABILITY

4.6.1 Data Review, Verification, and Validation
The purpose of the data quality review is to eliminate unacceptable analytical data and to designate a data qualifier for any data quality limitation discovered. The data quality review will include a review of laboratory performance criteria and sample-specific criteria. The reviewer will determine whether the measurement quality objectives have been met, and will calculate the data completeness for the project.
The data are reviewed in accordance with the criteria contained in the National Functional Guidelines for Superfund Organic Methods Data Review (EPA, 2014a), National Functional Guidelines for Inorganic Superfund Data Review (EPA, 2014b) and laboratory QC criteria (as applicable for each analytical method used). The data quality review will include verification of the following:

- Compliance with this SAP,
- Chain-of custody records,
- Case Narrative,
- Proper sample collection and handling procedures,
- Holding times,
- Field QC results,
- Laboratory blank analysis,
- MDLs and MRLs,
- Laboratory duplicate precision,
- MS/MSD recoveries,
- LCS recoveries,
- Surrogate compound recoveries,
- Data completeness and format, and
- Data qualifiers assigned by the laboratory.

Qualifiers will be added to data during the review as necessary. Qualifiers applied to the data as a result of the review will be limited to:

- **U** The analyte was analyzed for but was not detected above the reported sample quantitation limit.
- **J** The analyte was positively identified; the associated numerical value is the approximate concentration of the analyte in the sample.
- **UJ** The analyte was not detected above the method detection limit. However, the reporting limit is approximate and may or may not represent the actual limit of quantitation necessary to accurately and precisely measure the analyte in the sample.
- **R** The sample results are rejected due to serious deficiencies in the ability to analyze the sample and meet QC criteria.
- **DNR** Do Not Report. Another result is available that is more reliable.

The corrective action and flagging criteria as listed in the National Functional Guidelines will be used as guidance for applying the above flags to the samples results. A detailed summary of the data quality review will be included in the DQRR, which will provide an interpretation of the data quality, identify which sample results were flagged and why, as well as evaluate the need for corrective actions and/or comprehensive data validation.
4.6.2 Data Quality Review Report

After the field work, chemical analyses, and data quality reviews have been completed, the DQRR will be prepared. In this report, all data generated for this project will be reconciled with the project objectives. The report will include an evaluation of overall precision, accuracy, completeness, representativeness, comparability, and sensitivity of the sampling data; it will include an assessment of the overall usability of the data and describe any limitations on its use.

4.6.3 Documents and Records

All field activities will be recorded on the Monitoring Well Sampling Field Log (Appendix B). The field team will complete a Monitoring Well Sampling Field Log for each well. The Monitoring Well Sampling Field Log will be dated and signed by a field team representative. The Monitoring Well Sampling Field Log will include the following information:

- Field conditions, including temperature
- Well information
  - Date and time of sample collection,
  - The sample number, location, and ID,
  - Sample identification number, and
  - Any QC samples (i.e., field duplicates, extra mass or volume taken for MS/MSD) collected.
- Field measurements made.
- Field observations, especially any unexpected odors or stains,
- Any procedural steps taken that deviate from those outlined in this SAP, and
- Physical observations.
5.0 PROJECT MANAGEMENT

This section presents the overall management strategy for implementation of the groundwater monitoring. The section documents the responsibility and authority of each organization and key personnel involved with the implementation.

5.1 PROJECT ORGANIZATION AND RESPONSIBILITIES

The organizational structure and members of the team were selected to support the field, laboratory, and office tasks. The responsibilities and authorities of these key positions are described below.

- **DEQ Project Manager:** Mr. Jeff Schatz is the DEQ Project Manager (PM). Mr. Gainer will oversee the work performed by ARC and AECOM on behalf of the DEQ.
- **BP Environmental Project Manager:** Mr. Paul Supple is the ARC Environmental Project Manager.
- **AECOM Principal-in-Charge:** Mr. Mike Edwards, PE is the AECOM Principal-in-Charge (PIC).
- **AECOM Project Manager:** Mr. Scott Kranz, RG is the AECOM PM. The AECOM PM on behalf of ARC will oversee the development and implementation of the remedial action and is responsible for the environmental technical quality of the project. Mr. Kranz has overall responsibility for planning, scheduling, and managing costs of the field and reporting tasks and will be the lead in communicating with BP.
- **AECOM Field Manager:** Mr. Cliff Pearson is the AECOM Field Manager. The AECOM FM is responsible for coordinating and implementing field tasks in compliance with the Work Plan. This manager will schedule field activities and act as a liaison with contacts for the Owner. The FM will also be the Site Safety Officer (SSO) and is responsible for implementing the Health and Safety Plan (HASP).
- **AECOM Quality Assurance Manager for Analytical Chemistry:** Ms. Jeni Garcia is the QA Manager for analytical chemistry. She will oversee the subcontracted analytical testing laboratory and will direct the review of chemical data. She will work closely with the PM, the FM, and the analytical laboratory.
- **AECOM Office Health and Safety Manager:** Mr. Bruce Cassem is the AECOM office Health and Safety Manager. Mr. Cassem will work directly with the PM and FM and will be responsible for monitoring and verifying that the work is performed in accordance with the HASP. He will advise the AECOM PM and FM regarding health and safety issues but will function independently.
5.2 DOCUMENTATION AND REPORTING

Project activities will be documented in the project plans and project reports and will be supported by field oversight documentation forms and laboratory analytical reports. The AECOM PM is responsible for ensuring that effective document control procedures are established, implemented, and maintained. Laboratory documentation requirements are defined in the laboratory contracts and include details for data report composition, report format, and turnaround time.

5.2.1 Annual Groundwater Monitoring Reports

Annual groundwater monitoring reports will be provided to the DEQ each year. The annual groundwater monitoring reports will describe sampling activities and results, including:

- Summaries of field measurements and the list of monitoring wells sampled;
- Summaries of groundwater sample analytical results;
- Groundwater elevation maps for the shallow and deep zone groundwater;
- LPH thickness histograms;
- DQR reports; and
- Concentration trend charts for selected analytes.

Groundwater monitoring results will be evaluated in each annual groundwater monitoring report. Analytical results will be compared to human health and ecological SLVs and historical concentration trends will be presented.
6.0 REFERENCES


TABLES
### Table 3-1
Annual Groundwater Monitoring Program Summary
Groundwater Monitoring Sampling and Analysis Plan
BP Bulk Terminal 22T

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<th>Well ID</th>
<th>Screen Interval (feet bgs)</th>
<th>Lithologic Unit</th>
<th>Groundwater Zone</th>
<th>TPH-Dx w/ Silica Gel</th>
<th>TPH-Gx</th>
<th>BTEX and MTBE</th>
<th>EPA 8260B</th>
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<td>MD-07</td>
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<th>Well ID</th>
<th>Screen Interval (feet bgs)</th>
<th>Lithologic Unit</th>
<th>Groundwater Zone</th>
<th>TPH-Dx w/ Silica Gel</th>
<th>TPH-Gx</th>
<th>BTEX and MTBE</th>
<th>EPA 8260B</th>
<th>EPA 8270 SIM</th>
<th>Low Level PAHs</th>
<th>Total Metals</th>
<th>EPA 601/06020</th>
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<td>LPMW-03</td>
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<td>LPMW-05</td>
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</tbody>
</table>

### Notes:

*** DEQ Background Well
Total Metals\(^1\) = RCRA 8 Metals
bgs = below ground surface
BTEX = benzene, toluene, ethylbenzene, and xylenes
EPA = U.S. Environmental Protection Agency
LPA = Linnton Plywood Association
MS/MSD = matrix spike and matrix spike duplicate
MTBE = methyl tert-butyl ether
PAHs = polycyclic aromatic hydrocarbons
SIM = Selected Ion Monitoring
TBD = to be determined; LPMW-11 and -12 will be constructed as part of IRM
TPH-Dx = Diesel-range total petroleum hydrocarbons
TPH-Gx = Gasoline-range total petroleum hydrocarbons
<table>
<thead>
<tr>
<th>Analytical Parameter</th>
<th>Method</th>
<th>Container</th>
<th>Preservation</th>
<th>Holding Time</th>
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<td>BTEX and MTBE</td>
<td>EPA 8260</td>
<td>3 x 40 mL VOA</td>
<td>4 °C, HCl to pH&lt;2</td>
<td>14 days</td>
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<td>Low Level PAHs (parent)</td>
<td>EPA 8270-SIM</td>
<td>2 x 250 mL Amber Glass Bottle</td>
<td>4 °C</td>
<td>7 days to extraction</td>
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<td></td>
<td></td>
<td>40 to analysis</td>
</tr>
<tr>
<td>Total Metals</td>
<td>EPA 6010B/6020</td>
<td>250 mL HDPE</td>
<td>4 °C</td>
<td>180 days</td>
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<td>NWTPH-Dx with SGC</td>
<td>2 x 1 liter Amber Glass Bottle</td>
<td>4 °C</td>
<td>7 days to extraction</td>
</tr>
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<td></td>
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<td></td>
<td>30 to analysis</td>
</tr>
<tr>
<td>Total Petroleum Hydrocarbons – Gasoline-Range Organics</td>
<td>NWTPH-Gx</td>
<td>3 x 40 mL VOA</td>
<td>4 °C, HCl to pH&lt;2</td>
<td>7 days to extraction</td>
</tr>
<tr>
<td></td>
<td></td>
<td></td>
<td></td>
<td>14 to analysis</td>
</tr>
</tbody>
</table>

**Notes:**

1 = All glass containers will have Teflon-lines seals or septa
2 = Total Metals = RCRA 8 Metals
BTEX = Benzene, Toluene, Ethylbenzene, and Xylenes
°C = degrees Celsius
EPA = U.S. Environmental Protection Agency
HCL = hydrochloric acid
HDPE = High Density Polyethylene Bottles
mL = milliliter
MTBE = Methyl tert-butyl ether
PAHs = Polycyclic Aromatic Hydrocarbons
SGC = silica gel cleanup
VOA = Volatile Organic Analysis
< = less than
APPENDIX A – STANDARD OPERATING PROCEDURES
SOP 1
FIELD NOTES USE AND MAINTENANCE

1.0 SUMMARY
This procedure establishes a standard format for recording field observations and describes the methods for use and maintenance of the Daily Quality Control Reports (DQCRs).

DQCRs provide a means for recording all activities performed at a site and are intended to provide sufficient data and observations to enable reconstruction of events that occurred during performance of field activities. As such, all entries are to be as factual, detailed, and descriptive as appropriate so that a particular situation can be reconstructed without reliance on the author’s memory. DQCRs can be used to compare and check other field documents.

2.0 EQUIPMENT
- Daily Quality Control Reports
- Waterproof/indelible marking pen
- Ruler/straight edge
- Clipboard

3.0 PROCEDURE
3.1 Daily Quality Control Report Setup
The field team provides a permanent record of daily activities, observations, and measurements through the use of daily quality control reports. Individuals performing specific tasks associated with a field project may complete a separate daily quality control report; however, these forms must conform to this procedure and will become a permanent part of the project file. The Field Manager is responsible for reviewing all daily quality control reports associated with the project.

Data will be recorded using pens with permanent waterproof ink

The daily quality control reports will contain the following information:
- Report number
- Project name
- Project number
- Site name
- Date
- Company name
- Project manager
3.2 Daily Quality Control Report Entries

Daily entries will be made during field activities. One field team member will provide daily records of all significant events, observations, and measurements during field operations. Notes will start at the beginning of the first blank page and extend through as many pages as necessary.

All DQCR entries will be made in indelible black or blue ink. No erasures are permitted. If an incorrect entry is made, the data will be crossed out with a single line and initialed and dated by the originator. Entries can be organized into easily understood tables if necessary.

All DQCR pages will be signed and dated at the bottom. Times will be recorded next to each entry. If a full page is not used during the course of a workday, a diagonal line will be drawn through the unused portion of the page and signed (in this case, it would not be necessary to sign the bottom of the page).

All entries on the DQCRs will be chronological, using a 24-hour clock. Field personnel will start a new daily quality control report at the beginning of each new workday. If more than one person makes entries on a daily quality control report, each person will provide a signature at the end of the section that the person is responsible for authoring.

Copies or duplicate backups of DQCRs should be made daily if possible or, at a minimum, once a week to avoid loss of information that may be costly to replace or reconstruct.

At a minimum, DQCR entries will include the following information at the beginning of each day as appropriate to the activities:

- Date
- Project name and number
- Start time
- Weather
- Daily health and safety meeting notes
- Field activities to be performed
- Field observations
- Field measurements (pH, temperature, conductivity, etc.)
- Methods used for equipment decontamination
- Procedures used for containerization of investigation-derived waste
- All field personnel present and directly involved
- Visitors to the site (including times)
- Level of personal protective equipment used on the site
- Equipment used and procedures followed
• Signature of the person making the entry

When samples are collected, the following information must be included:

• Location of sample
• Samplers’ printed names and signatures
• Date and time of sample collection
• Sample identification/number
• Description of sample matrix
• Sample depth
• Sampling methods
• Sample handling, including filtration and preservation
• Analytical analysis required
SOP 2
SAMPLE HANDLING, LABELING, PACKAGING, AND SHIPPING

1.0 SUMMARY

This procedure defines the standard protocols for sample handling, labeling, packaging, and shipping of environmental samples prior to their delivery to an analytical laboratory.

2.0 EQUIPMENT

Equipment and materials used for sample labeling, packaging, and shipping include the following:

- Waterproof coolers (hard plastic or metal)
- Custody seals
- Field forms such as Daily Quality Control Report (DQCR), Chain-of-Custody (COC), and other relevant field data forms
- Ice or blue ice pack
- Packing material such as bubble wrap and bubble bags
- Clear tape for labels and duct tape to seal coolers
- Zipper-locking plastic bags (quart and gallon size)
- Garbage bags (33-45 gallon)
- Sample containers
- Sample labels
- Waterproof and permanent marking pens

3.0 PROCEDURES

The DQCRs are used to document all pertinent information regarding sample handling, labeling, packaging and shipping.

3.1 Sample Handling

Commercially certified clean sample containers are obtained from the contract analytical laboratory. The laboratory will indicate the type of sample to be collected in each bottle and add chemical preservatives, if necessary, to the sample containers prior to shipment to the field. Preserved samples will be stored on ice in coolers and the sample temperature will be maintained at 4 degrees Celsius (± 2 degrees) (4°C ± 2°C). Samples should not be overcooled (i.e., should not be frozen).
3.2 Sample Labeling

Prepare a label for each sample collected and apply the label to the sample container. Labels require some or all of the following information:

- Project name
- Project number
- Unique sample ID
- Date of sampling
- Time of sample collection
- Analyses to be performed (be as specific as possible)
- Whether filtered or unfiltered (water sample only)
- Preservatives (water sample only)
- Sample matrix (soil, water, sediment, etc.)

3.3 Sample Packaging and Shipping

The samples will be packed in coolers using bubble wrap and ice packs or crushed ice to maintain samples at 4 degrees Celsius during transport to the laboratory.

In order to ensure that samples arrive at the laboratory intact and at the proper temperature (4°C ± 2°C) the following steps should be followed:

1. Check the cap tightness and affix a custody seal to each sample container.
2. For glass sample containers, wrap the container in protective packing material such as bubble wrap or bubble bags (or VOC vial foam container for VOC vials only).
3. When applicable, enclose individual sample containers in a zipper-locking plastic bag (i.e. low-level metal analyses).
4. Line the cooler with an open garbage bag. Place the samples right side up in the bag. Remove as much air as possible and seal the garbage bag.
5. Place bags of ice in the cooler, on the outside of the garbage bag containing the samples.
6. Ensure that there is no void space remaining in the cooler. Add additional packing material to prevent movement or breakage of the sample jars during shipment. Gently bounce the cooler to ensure that the cooler contents have settled.
7. Make copies of all documents being sent to the laboratory or remove and retain carbonless copies. Enclose the completed COC form, or other documents required by the contract in a zipper-locking plastic bag and tape the bag to the underside of
the cooler lid. It is imperative that the samples contained in the cooler and the samples listed on the COC form are identical.

8. Seal the cooler with tape and affix at least two signed and dated custody seals so that if the cooler were opened, the custody seals would be broken. Place clear tape over the custody seals to prevent damage to the seals.

Samples will be hand delivered via laboratory courier or shipped overnight express to the laboratory. All samples must be delivered to the laboratory within the specific holding times. Daily shipment of samples with short holding times may be required.

Special shipping requirements may apply to sample containers containing certain preservatives. Follow laboratory guidelines for conforming with International Air Transport Association requirements.

4.0 DOCUMENTATION

Complete copies of shipping receipts and associated COC form are retained in the field. A copy of each completed sample collection information form, COC form and shipping receipt will be forwarded to the main project file within 5 days of the sample shipment.
SOP 3
SAMPLE CONTROL, DOCUMENTATION, AND TRACKING

1.0 PURPOSE

The purpose of this procedure is to describe the proper sample control, documentation, and tracking methods to be followed for environmental projects. This procedure outlines the documentation necessary to trace sample possession and shipment.

This procedure provides guidance for routine field operations. Site-specific deviations from the methods presented herein must be approved by the URS Quality Assurance (QA) Manager.

2.0 EQUIPMENT

Chain-of-custody (COC) form.

3.0 PROCEDURES

Field personnel (samplers) are responsible for performing the tasks in accordance with this procedure. These personnel are responsible for the care and custody of the collected samples until the samples are transferred or dispatched properly. All activities and data collected shall be recorded in the Daily Quality Control Report (DQCR).

The URS Field Manager (FM) or an approved designee is responsible for checking all work performance and verifying that the work satisfies the applicable tasks required in this procedure. This will be accomplished by reviewing all documents and data produced.

3.1 Sample Custody

Written documentation of sample custody from the time of sample collection through the generation of data by analysis of that sample is a vital aspect of an environmental study. Official custody of samples must be maintained from the time of sample collection until the time the samples are introduced as evidence in the event of litigation. Field personnel are responsible for the care and custody of the samples until sample shipment. The COC form is used as physical evidence of sample custody. A sample or evidence file is under custody if it is in:

- The possession of the sampler/analyst
- View of the sampler/analyst
- A designated secure area

Sample custody consists of three parts: sample collection, laboratory analysis, and final evidence files. The COC of the physical sample and its corresponding documentation must be maintained throughout the handling of the sample. Through accurate accounting of the sample custody, the record of the physical sample (location and time of sampling) can be joined with the analytical results.
As a part of the procedure to ensure the integrity of the resulting data, the field personnel must identify, label, and log onto a COC form all samples. The COC form documents samples that are shipped to laboratories under contract to URS. Use waterproof ink unless prohibited by weather conditions. For example, a DQCR notation will explain that a pencil was used to fill out the sample tag because the ballpoint pen would not function in freezing weather.

3.2 Samples and Sample Name

Samples are collected as described in the QAPP. In general, a sample is defined by matrix (such as sludge, water, soil). The sample is further defined as consisting of all the sample aliquots (for multiple analyses) from one station location, for each matrix. All sample containers collected from a single location for a single matrix have the same sample name.

REMEMBER:

- COC forms must be used with every shipment of samples to each laboratory.

3.3 Transfer of Custody and Sample Tracking Procedures

All samples must be accompanied by a properly completed COC form. When transferring the possession of samples, the individuals relinquishing and receiving will sign, date, and note the time on the record. This record documents transfer of custody of samples from the sampler to another person or to the laboratory.

Properly package samples for shipment and dispatch to the designated laboratory for analysis. Include a copy of the COC form (signed by the person releasing the samples) in a waterproof container (e.g. ziplock bag) on top of the samples in the cooler. Secure shipping containers with strapping tape. Place custody seals on the shipping container for shipment to the laboratory. The preferred procedure is the attachment of a custody seal to the front right and back left of the cooler. Cover the custody seals with clear plastic tape. Strap the cooler shut with strapping tape in at least two locations.

If the samples are sent by common carrier, follow appropriate federal regulations (i.e., IATA). Commercial carriers are not required to sign off on the COC form as long as the form is sealed inside the sample cooler and the custody seals remain intact.

3.4 Review

The field personnel are responsible for the care and custody of the samples until they are transferred or properly dispatched. As few people as possible should handle the samples. The sampler is also responsible for reviewing (or for having a second sampler review) the custody forms for completeness and accuracy before relinquishing custody.

The URS QA Manager or an approved designee must review all field activities to determine whether proper COC procedures were followed during the field work and to decide if additional samples are required. The sampler should notify the URS FM of a breach or irregularity in chain of custody procedures. The URS Project Manager (PM) will notify the client, as required.
4.0 DOCUMENTATION

The URS FM will retain the appropriate copies of the COC forms and requests for analyses forms as marked on the bottom of each of the forms.
SOP 4

WELL WATER LEVEL MEASUREMENT

1.0 PURPOSE

The purpose of this procedure is to describe the field methods for gauging static water levels and product accumulations in monitoring wells. All wells should be considered to contain contaminated groundwater and therefore proper decontamination procedures shall be followed.

2.0 EQUIPMENT

- The following equipment is required for water level gauging:
  - Four Gas Meter
  - Hand tools to open well vaults/monuments
  - Nitrile Gloves
  - PVC gloves (outer) for system wells
  - Oil/water Interface Probe
  - Simple Green cleaner
  - Dilute Alconox solution (or equivalent detergent-potable water mixture)
  - Distilled or deionized (DI) water
  - Oil-absorbent pads
  - Clipboard and pen.

3.0 FORMS REQUIRED

The Well Data Collection Form is required.

4.0 PROCEDURES

4.1 Select and Decontaminate Equipment

- All water/product level and decontamination equipment is kept in the equipment compound that is located in the warehouse.

- Select the Oil/Water Interface Probe(s) that will be used for collecting data and record the instrument manufacturer and model number on the Well Data Collection Form.
- Remove visible contamination by wiping equipment with Simple Green and an oil-absorbent pad.
- Soap wash (dilute Alconox solution [or equivalent detergent-potable water mixture]) probe and the first several feet of the tape (i.e. any part of the instrument which has contacted product or groundwater).
- Distilled/DI water rinse.
- Second distilled/DI water rinse. Repeat as necessary to decontaminate the equipment.

4.2 Gauge Wells

- Set one or more delineators around the well, depending on the well vault size and how long you plan to be at that well.
- Remove the well monument/ open vault lid.

**CAUTION: BE CAREFUL WHEN OPENING VAULT LIDS IN ORDER TO PREVENT INJURY TO BACK OR FINGERS**

- Use the four gas meter to check for abnormal atmospheric conditions inside and/or around the well vault. If all conditions are normal, mark an asterisk on the gauging form to note that conditions were verified prior to collecting groundwater measurements. If any unusual conditions were noted, comment on the well gauging form and wait to see if conditions assimilate to normal atmospheric conditions prior to conducting further work in/or around the well vault.
- Remove water inside the monument, vaults that might reach the well head and flow down the well casing. Note quantity/level on the Well Data Collection Form.
- Carefully remove the well cap – some wells may be pressurized or under vacuum (note on Well Data Collection Form).
- Before measuring the static water levels, allow for equalization of atmospheric pressure and stabilization of the groundwater surface. If the down hole equipment must be removed before gauging or the well plug has a vacuum or pressure. The time required for this varies across the site.
- Measure the depth from the top of casing (TOC) to the static product/water level with a water probe or oil/water interface probe. Reference points have been marked on the TOC of each well. If the reference mark has worn off, measure to the side of the casing closest to the river.
- Record the depth to product and water measurements on the Well Data Collection
Form, along with the time of measurement and any comments.

- Decontaminate the probe and any portion of the tape which may have contacted product or groundwater. Refer to Section 4.1.
- **Replace the well cap securely on the well.**
- Replace the monument/close the vault lid. Make sure lid is flush before moving on.

### 4.3 Decontaminate Equipment

- Soap wash (dilute Alconox solution [or equivalent detergent-potable water mixture]) probe and the first several feet of the tape (i.e. any part of the instrument which has contacted product or groundwater).
- Distilled/DI water rinse.
- Second distilled/DI water rinse.
- Repeat as necessary to decontaminate the equipment before placing it back into the equipment compound.

### 5.0 SPECIAL CONSIDERATIONS

- Tools and supplies are kept in the Equipment Compound of the warehouse.

### 6.0 DOCUMENTATION

Water level and product depth measurements are documented on the Well Data Collection Form.
SOP 5
FIELD AND LABORATORY QUALITY CONTROL SAMPLE COLLECTION

1.0 PURPOSE

The purpose of this procedure is to define the field quality control (QC) and laboratory QC samples that will be employed to evaluate data quality. Quality control samples are controlled samples introduced into the analysis stream, whose results are used to review data quality and to calculate the accuracy and precision of the chemical analysis program. The purpose of each type of QC sample collection and typical analysis frequency is described in this procedure. Collection and analysis frequency for quality control samples is summarized in the Work Plan.

2.0 EQUIPMENT

The equipment required for the collection of QC samples is identical to the equipment required for the collection of environmental samples, with the addition of the following:

- Laboratory issued trip blanks (if applicable)
- Multiple 5 gallon carboys of laboratory-grade distilled/deionized (DS/DI) water (organic/analyte-free) – provided by the laboratory

3.0 PROCEDURES

3.1 Field Quality Control Samples

The types of QC samples that are sent to the laboratory (when applicable) from the field are field blanks, trip blanks, rinsate (equipment) blanks, field replicates, standard reference samples, and temperature blanks.

3.2 Field Blanks

Field blanks are used to determine if contamination is introduced into samples by general field procedures. Field blanks are prepared on site during the sampling event by pouring laboratory provided DS/DI water into randomly selected sample containers. Typically, at least one field blank is analyzed for each group of 20 samples of a similar matrix type and concentration.

3.2.1 Trip Blanks

Trip blanks are used to assess contamination introduced into the sample containers by the diffusion of volatile organic compounds (VOCs) during sample transport and storage. One trip blank is prepared off site (preferably at the contracted analytical laboratory) and included in each shipping container with samples scheduled for analysis of VOCs, regardless of the environmental medium. When sample bottles are provided by the laboratory, trip blanks are prepared at the laboratory, transported to the sampling site with the other sample containers, and returned to the testing laboratory for analysis, along with the samples collected during the sampling event. The
trip blanks remain unopened throughout the transportation and storage processes and are analyzed along with the associated environmental samples. Trip blanks are analyzed and reported as water samples, even though the associated environmental samples may be from a matrix such as soil, tissue, or product.

3.2.2 Rinsate Blanks

Rinsate blanks (equipment decontamination rinsates) are used to assess the adequacy of the practices for preventing cross-contamination between sampling locations and samples. Rinsate blanks are collected daily for sampling equipment used repetitively to collect environmental samples and are not collected for dedicated sampling equipment or drilling equipment. Rinsate blanks for soil, sediment, groundwater, seep, and surface water samples are collected by passing laboratory provided DS/DI water over all sampling equipment (such as a bailer, sampling pump, or mixing bowl) following the final decontamination rinse and collecting the water into the sample containers specified for each analysis. One rinsate blank will be analyzed on each type of sampling equipment (stainless steel bowl, hand trowel, etc.) Rinsate blanks are preserved, handled, and analyzed in the same manner as environmental samples.

3.2.3 Field Duplicates

Field duplicates (or replicates) are collected at selected locations to provide estimates of the total sampling and analytical precision. Typically, at least 1 duplicate sample is analyzed from each group of 20 samples of a similar matrix type and concentration. Field duplicate samples should generally be collected from areas most likely to be contaminated and are preserved, handled, and analyzed in the same manner as all environmental samples. Field duplicates have the same location identification, sampling time, and depth interval as the associated environmental sample, but are assigned a unique sample number from the associated environmental sample number. Field duplicates are submitted blind to the laboratory.

3.2.4 Temperature Blanks

Temperature blanks are used to measure cooler temperatures upon receipt of the coolers at the laboratory. One temperature blank will be prepared and submitted to the project laboratory with each cooler. The temperature blank will consist of a sample jar containing water, which will be packed in the cooler in the same manner as the rest of the samples and labeled “temperature blank.”

3.3 Laboratory Quality Control Samples

The analytical laboratory uses a series of QC samples specified in each standard analytical method and laboratory SOP to assess laboratory performance. Analyses of laboratory QC samples are performed for samples of similar matrix type and concentration and for each sample batch. The types of laboratory QC samples are matrix spike/matrix spike duplicates, laboratory control samples, laboratory duplicates, method blanks, and surrogate spikes. In addition, there may be other project-specific technical QC requirements.
3.3.1 Matrix Spike/Matrix Spike Duplicate

Matrix spike/matrix spike duplicates (MS/MSDs) are used to assess sample matrix interferences and analytical errors, as well as to measure the accuracy and precision of the analysis. For MS or MSD samples, known concentrations of analytes are added to the environmental samples; the samples are then processed through the entire analytical procedure and the recovery of the analytes is calculated. Results are expressed as percent recovery of the known spiked amount for MSs and the relative percent difference (RPD) for MS/MSD pair. The MS/MSDs will be collected and analyzed at a rate of 5 percent of the field samples for each matrix and analytical method or at least one for each analytical batch, whichever frequency is greater.

Generally, a single sampling location is used to collect field QC samples. Samples designated for MS/MSD analyses will not be collected from locations with potentially high concentrations of target analytes that may mask the added spike compounds. MS/MSD samples have the same location identification, sampling time, depth interval, and sample number as the associated environmental sample.

3.3.2 Laboratory Control Samples

Laboratory control samples (LCSs) are used to monitor the laboratory’s day-to-day performance of routine analytical methods, independent of matrix effects. The LCSs are prepared by spiking reagent water with standard solutions prepared independently of the standard solutions used in establishing instrument calibration. The LCSs are extracted and analyzed with each batch of samples. Results are compared on a per-batch basis and used to evaluate laboratory performance for accuracy. LCSs may also be used to identify any background contamination of the analytical system that may lead to the reporting of elevated concentrations or false-positive measurements.

3.3.3 Laboratory Duplicates

Laboratory duplicates are used to determine the precision of the analytical system. Laboratory duplicates are two portions of a single homogeneous sample analyzed for the same parameter. Laboratory duplicates are prepared and analyzed with each analytical batch of project samples that do not require MSDs.

3.3.4 Method Blanks

Method blanks are used to check for laboratory contamination and instrument bias. Laboratory method blanks are typically analyzed at a minimum frequency of 5 percent or one per analytical batch for all chemical parameter groups. Blank samples are analyzed for the same parameters as the associated field samples.

3.3.5 Surrogate Spikes

Surrogate spikes are used to evaluate the accuracy of an analytical measurement. Surrogate compounds are compounds that are not expected to be found in environmental samples; however, they are chemically similar to several compounds analyzed by the methods and behave similarly in extracting solvents. Samples are spiked with surrogate compounds consistent with the
requirements described in the analytical methods and in the laboratory SOPs. Because sample characteristics affect the percent recovery of the surrogate compounds, the percent recovery is a measure of the accuracy of the overall analytical method on each individual sample.

4.0 DOCUMENTATION

The collection of field quality control samples is documented in the Daily Quality Control Report.
SOP 6
LOW-FLOW GROUNDWATER SAMPLING

1.0 SUMMARY

See attached EPA/540/S-95/504
Ground Water Issue

LOW-FLOW (MINIMAL DRAWDOWN) GROUND-WATER SAMPLING PROCEDURES

by Robert W. Puls¹ and Michael J. Barcelona²

Background

The Regional Superfund Ground Water Forum is a group of ground-water scientists, representing EPA’s Regional Superfund Offices, organized to exchange information related to ground-water remediation at Superfund sites. One of the major concerns of the Forum is the sampling of ground water to support site assessment and remedial performance monitoring objectives. This paper is intended to provide background information on the development of low-flow sampling procedures and its application under a variety of hydrogeologic settings. It is hoped that the paper will support the production of standard operating procedures for use by EPA Regional personnel and other environmental professionals engaged in ground-water sampling.

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I. Introduction

The methods and objectives of ground-water sampling to assess water quality have evolved over time. Initially the emphasis was on the assessment of water quality of aquifers as sources of drinking water. Large water-bearing units were identified and sampled in keeping with that objective. These were highly productive aquifers that supplied drinking water via private wells or through public water supply systems. Gradually, with the increasing awareness of subsurface pollution of these water resources, the understanding of complex hydrogeochemical processes which govern the fate and transport of contaminants in the subsurface increased. This increase in understanding was also due to advances in a number of scientific disciplines and improvements in tools used for site characterization and ground-water sampling. Ground-water quality investigations where pollution was detected initially borrowed ideas, methods, and materials for site characterization from the water supply field and water analysis from public health practices. This included the materials and manner in which monitoring wells were installed and the way in which water was brought to the surface, treated, preserved and analyzed. The prevailing conceptual ideas included convenient generalizations of ground-water resources in terms of large and relatively homogeneous hydrologic units. With time it became apparent that conventional water supply generalizations of homogeneity did not adequately represent field data regarding pollution of these subsurface resources. The important role of heterogeneity became increasingly clear not only in geologic terms, but also in terms of complex physical,

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chemical and biological subsurface processes. With greater appreciation of the role of heterogeneity, it became evident that subsurface pollution was ubiquitous and encompassed the unsaturated zone to the deep subsurface and included unconsolidated sediments, fractured rock, and aquifers or low-yielding or impermeable formations. Small-scale processes and heterogeneities were shown to be important in identifying contaminant distributions and in controlling water and contaminant flow paths.

It is beyond the scope of this paper to summarize all the advances in the field of ground-water quality investigations and remediation, but two particular issues have bearing on ground-water sampling today: aquifer heterogeneity and colloidal transport. Aquifer heterogeneities affect contaminant flow paths and include variations in geology, geochemistry, hydrology and microbiology. As methods and the tools available for subsurface investigations have become increasingly sophisticated and understanding of the subsurface environment has advanced, there is an awareness that in most cases a primary concern for site investigations is characterization of contaminant flow paths rather than entire aquifers. In fact, in many cases, plume thickness can be less than a few hundred meters (e.g., 3-6 m) typically installed at hazardous waste sites to detect and monitor plume movement over time. Small-scale differences have increasingly been shown to be important and there is a general trend toward smaller diameter wells and shorter screens.

The hydrogeochemical significance of colloidal-size particles in subsurface systems has been realized during the past several years (Gschwend and Reynolds, 1987; McCarthy and Zachara, 1989; Puls, 1990; Ryan and Gschwend, 1990). This realization resulted from both field and laboratory studies that showed faster contaminant migration over greater distances and at higher concentrations than flow and transport model predictions would suggest (Buddemeier and Hunt, 1988; Enfield and Bengtsson, 1988; Penrose et al., 1990). Such models typically account for interaction between the mobile aqueous and immobile solid phases, but do not allow for a mobile, reactive solid phase. It is recognition of this third phase as a possible means of contaminant transport that has brought increasing attention to the manner in which samples are collected and processed for analysis (Puls et al., 1990; McCarthy and Degueilire, 1993; Baechus et al., 1993; U. S. EPA, 1995). If such a phase is present in sufficient mass, possesses high sorption reactivity, large surface area, and remains stable in suspension, it can serve as an important mechanism to facilitate contaminant transport in many types of subsurface systems.

Colloids are particles that are sufficiently small so that the surface free energy of the particle dominates the bulk free energy. Typically, in ground water, this includes particles with diameters between 1 and 1000 nm. The most commonly observed mobile particles include: secondary clay minerals; hydrors, iron, aluminum, and manganese oxides; dissolved and particulate organic materials, and viruses and bacteria. These reactive particles have been shown to be mobile under a variety of conditions in both field studies and laboratory column experiments, and as such need to be included in monitoring programs where identification of the total mobile contaminant loading (dissolved + naturally suspended particles) at a site is an objective. To that end, sampling methodologies must be used which do not artificially bias naturally suspended particle concentrations.

Currently the most common ground-water purging and sampling methodology is to purge a well using bailers or high speed pumps to remove 3 to 5 casing volumes followed by sample collection. This method can cause adverse impacts on sample quality through collection of samples with high levels of turbidity. This results in the inclusion of otherwise immobile artifactual particles which produce an overestimation of certain analytes of interest (e.g., metals or hydrophobic organic compounds). Numerous documented problems associated with filtration (Danielsson, 1982; Laken and Chandler, 1982; Horowitz et al., 1992) make this an undesirable method of rectifying the turbidity problem, and include the removal of potentially mobile (contaminant-associated) particles during filtration, thus artificially biasing contaminant concentrations low. Sampling-induced turbidity problems can often be mitigated by using low-flow purging and sampling techniques.

Current subsurface conceptual models have undergone considerable refinement due to the recent development and increased use of field screening tools. So-called hydraulic push technologies (e.g., cone penetrometer, Geoprobe®, QED HydroPunch®) enable relatively fast screening site characterization which can then be used to design and install a monitoring well network. Indeed, alternatives to conventional monitoring wells are now being considered for some hydrogeologic settings. The ultimate design of any monitoring system should however be based upon adequate site characterization and be consistent with established monitoring objectives.

If the sampling program objectives include accurate assessment of the magnitude and extent of subsurface contamination over time and/or accurate assessment of subsequent remedial performance, then some information regarding plume delineation in three-dimensional space is necessary prior to monitoring well network design and installation. This can be accomplished with a variety of different tools and equipment ranging from hand-operated augers to screening tools mentioned above and large drilling rigs. Detailed information on ground-water flow velocity, direction, and horizontal and vertical variability are essential baseline data requirements. Detailed soil and geologic data are required prior to and during the installation of sampling points. This includes historical as well as detailed soil and geologic logs which accumulate during the site investigation. The use of borehole geophysical techniques is also recommended. With this information (together with other site characterization data) and a clear understanding of sampling
objectives, then appropriate location, screen length, well diameter, slot size, etc. for the monitoring well network can be decided. This is especially critical for new in situ remedial approaches or natural attenuation assessments at hazardous waste sites.

In general, the overall goal of any ground-water sampling program is to collect water samples with no alteration in water chemistry; analytical data thus obtained may be used for a variety of specific monitoring programs depending on the regulatory requirements. The sampling methodology described in this paper assumes that the monitoring goal is to sample monitoring wells for the presence of contaminants and it is applicable whether mobile colloids are a concern or not and whether the analytes of concern are metals (and metalloids) or organic compounds.

II. Monitoring Objectives and Design Considerations

The following issues are important to consider prior to the design and implementation of any ground-water monitoring program, including those which anticipate using low-flow purging and sampling procedures.

A. Data Quality Objectives (DQOs)

Monitoring objectives include four main types: detection, assessment, corrective-action evaluation and resource evaluation, along with hybrid variations such as site-assessments for property transfers and water availability investigations. Monitoring objectives may change as contamination or water quality problems are discovered. However, there are a number of common components of monitoring programs which should be recognized as important regardless of initial objectives. These components include:

1) Development of a conceptual model that incorporates elements of the regional geology to the local geologic framework. The conceptual model development also includes initial site characterization efforts to identify hydrostratigraphic units and likely flow-paths using a minimum number of borings and well completions;

2) Cost-effective and well documented collection of high quality data utilizing simple, accurate, and reproducible techniques; and

3) Refinement of the conceptual model based on supplementary data collection and analysis.

These fundamental components serve many types of monitoring programs and provide a basis for future efforts that evolve in complexity and level of spatial detail as purposes and objectives expand. High quality, reproducible data collection is a common goal regardless of program objectives.

High quality data collection implies data of sufficient accuracy, precision, and completeness (i.e., ratio of valid analytical results to the minimum sample number called for by the program design) to meet the program objectives. Accuracy depends on the correct choice of monitoring tools and procedures to minimize sample and subsurface disturbance from collection to analysis. Precision depends on the repeatability of sampling and analytical protocols. It can be assured or improved by replication of sample analyses including blanks, field/lab standards and reference standards.

B. Sample Representativeness

An important goal of any monitoring program is collection of data that is truly representative of conditions at the site. The term representativeness applies to chemical and hydrogeologic data collected via wells, borings, piezometers, geophysical and soil gas measurements, lysimeters, and temporary sampling points. It involves a recognition of the statistical variability of individual subsurface physical properties, and contaminant or major ion concentration levels, while explaining extreme values. Subsurface temporal and spatial variability are facts. Good professional practice seeks to maximize representativeness by using proven accurate and reproducible techniques to define limits on the distribution of measurements collected at a site. However, measures of representativeness are dynamic and are controlled by evolving site characterization and monitoring objectives. An evolutionary site characterization model, as shown in Figure 1, provides a systematic approach to the goal of consistent data collection.

![Figure 1. Evolutionary Site Characterization Model](image)

The model emphasizes a recognition of the causes of the variability (e.g., use of inappropriate technology such as using bailers to purge wells; imprecise or operator-dependent methods) and the need to control avoidable errors.
1) Questions of Scale

A sampling plan designed to collect representative samples must take into account the potential scale of changes in site conditions through space and time as well as the chemical associations and behavior of the parameters that are targeted for investigation. In subsurface systems, physical (i.e., aquifer) and chemical properties over time or space are not statistically independent. In fact, samples taken in close proximity (i.e., within distances of a few meters) or within short time periods (i.e., more frequently than monthly) are highly auto-correlated. This means that designs employing high-sampling frequency (e.g., monthly) or dense spatial monitoring designs run the risk of redundant data collection and misleading inferences regarding trends in values that aren’t statistically valid. In practice, contaminant detection and assessment monitoring programs rarely suffer these over-sampling concerns. In corrective-action evaluation programs, it is also possible that too little data may be collected over space or time. In these cases, false interpretation of the spatial extent of contamination or underestimation of temporal concentration variability may result.

2) Target Parameters

Parameter selection in monitoring program design is most often dictated by the regulatory status of the site. However, background water quality constituents, purging indicator parameters, and contaminants, all represent targets for data collection programs. The tools and procedures used in these programs should be equally rigorous and applicable to all categories of data, since all may be needed to determine or support regulatory action.

C. Sampling Point Design and Construction

Detailed site characterization is central to all decision-making purposes and the basis for this characterization resides in identification of the geologic framework and major hydro-stratigraphic units. Fundamental data for sample point location include: subsurface lithology, head-differences and background geochemical conditions. Each sampling point has a proper use or uses which should be documented at a level which is appropriate for the program’s data quality objectives. Individual sampling points may not always be able to fulfill multiple monitoring objectives (e.g., detection, assessment, corrective action).

1) Compatibility with Monitoring Program and Data Quality Objectives

Specifics of sampling point location and design will be dictated by the complexity of subsurface lithology and variability in contaminant and/or geochemical conditions. It should be noted that, regardless of the ground-water sampling approach, few sampling points (e.g., wells, drive-points, screened augers) have zones of influence in excess of a few feet. Therefore, the spatial frequency of sampling points should be carefully selected and designed.

2) Flexibility of Sampling Point Design

In most cases well-point diameters in excess of 1 7/8 inches will permit the use of most types of submersible pumping devices for low-flow (minimal drawdown) sampling. It is suggested that short (e.g., less than 1.6 m) screens be incorporated into the monitoring design where possible so that comparable results from one device to another might be expected. Short, of course, is relative to the degree of vertical water quality variability expected at a site.

3) Equilibration of Sampling Point

Time should be allowed for equilibration of the well or sampling point with the formation after installation. Placement of well or sampling points in the subsurface produces some disturbance of ambient conditions. Drilling techniques (e.g., auger, rotary, etc.) are generally considered to cause more disturbance than direct-push technologies. In either case, there may be a period (i.e., days to months) during which water quality near the point may be distinctly different from that in the formation. Proper development of the sampling point and adjacent formation to remove fines created during emplacement will shorten this water quality recovery period.

III. Definition of Low-Flow Purging and Sampling

It is generally accepted that water in the well casing is non-representative of the formation water and needs to be purged prior to collection of ground-water samples. However, the water in the screened interval may indeed be representative of the formation, depending upon well construction and site hydrogeology. Wells are purged to some extent for the following reasons: the presence of the air interface at the top of the water column resulting in an oxygen concentration gradient with depth, loss of volatiles up the water column, leaching from or sorption to the casing or filter pack, chemical changes due to clay seals or backfill, and surface infiltration. Low-flow purging, whether using portable or dedicated systems, should be done using pump-intake located in the middle or slightly above the middle of the screened interval. Placement of the pump too close to the bottom of the well will cause increased entrainment of solids which have collected in the well over time. These particles are present as a result of well development, prior purging and sampling events, and natural colloidal transport and deposition. Therefore, placement of the pump in the middle or toward the top of the screened interval is suggested. Placement of the pump at the top of the water column for sampling is only recommended in unconfined aquifers, screened across the water table, where this is the desired sampling point. Low-
flow purging has the advantage of minimizing mixing between the overlying stagnant casing water and water within the screened interval.

A. Low-Flow Purging and Sampling

Low-flow refers to the velocity with which water enters the pump intake and that is imparted to the formation pore water in the immediate vicinity of the well screen. It does not necessarily refer to the flow rate of water discharged at the surface which can be affected by flow regulators or restrictions. Water level drawdown provides the best indication of the stress imparted by a given flow-rate for a given hydrological situation. The objective is to pump in a manner that minimizes stress (drawdown) to the system to the extent practical taking into account established site sampling objectives. Typically, flow rates on the order of 0.1 - 0.5 L/min are used, however this is dependent on site-specific hydrogeology. Some extremely coarse-textured formations have been successfully sampled in this manner at flow rates to 1 L/min. The effectiveness of using low-flow purging is intimately linked with proper screen location, screen length, and well construction and development techniques. The reestablishment of natural flow paths in both the vertical and horizontal directions is important for correct interpretation of the data. For high resolution sampling needs, screens less than 1 m should be used. Most of the need for purging has been found to be due to passing the sampling device through the overlying casing water which causes mixing of these stagnant waters and the dynamic waters within the screened interval. Additionally, there is disturbance to suspended sediment collected in the bottom of the casing and the displacement of water out into the formation immediately adjacent to the well screen. These disturbances and impacts can be avoided using dedicated sampling equipment, which precludes the need to insert the sampling device prior to purging and sampling.

Isolation of the screened interval water from the overlying stagnant casing water may be accomplished using low-flow minimal drawdown techniques. If the pump intake is located within the screened interval, most of the water pumped will be drawn in directly from the formation with little mixing of casing water or disturbance to the sampling zone. However, if the wells are not constructed and developed properly, zones other than those intended may be sampled. At some sites where geologic heterogeneities are sufficiently different within the screened interval, higher conductivity zones may be preferentially sampled. This is another reason to use shorter screened intervals, especially where high spatial resolution is a sampling objective.

B. Water Quality Indicator Parameters

It is recommended that water quality indicator parameters be used to determine purging needs prior to sample collection in each well. Stabilization of parameters such as pH, specific conductance, dissolved oxygen, oxidation-reduction potential, temperature and turbidity should be used to determine when formation water is accessed during purging. In general, the order of stabilization is pH, temperature, and specific conductance, followed by oxidation-reduction potential, dissolved oxygen and turbidity. Temperature and pH, while commonly used as purging indicators, are actually quite insensitive in distinguishing between formation water and stagnant casing water; nevertheless, these are important parameters for data interpretation purposes and should also be measured. Performance criteria for determination of stabilization should be based on water-level drawdown, pumping rate and equipment specifications for measuring indicator parameters. Instruments are available which utilize in-line flow cells to continuously measure the above parameters.

It is important to establish specific well stabilization criteria and then consistently follow the same methods thereafter, particularly with respect to drawdown, flow rate and sampling device. Generally, the time or purge volume required for parameter stabilization is independent of well depth or well volumes. Dependent variables are well diameter, sampling device, hydrogeochemistry, pump flow rate, and whether the devices are used in a portable or dedicated manner. If the sampling device is already in place (i.e., dedicated sampling systems), then the time and purge volume needed for stabilization is much shorter. Other advantages of dedicated equipment include less purge water for waste disposal, much less decontamination of equipment, less time spent in preparation of sampling as well as time in the field, and more consistency in the sampling approach which probably will translate into less variability in sampling results. The use of dedicated equipment is strongly recommended at wells which will undergo routine sampling over time.

If parameter stabilization criteria are too stringent, then minor oscillations in indicator parameters may cause purging operations to become unnecessarily protracted. It should also be noted that turbidity is a very conservative parameter in terms of stabilization. Turbidity is always the last parameter to stabilize. Excessive purge times are invariably related to the establishment of too stringent turbidity stabilization criteria. It should be noted that natural turbidity levels in ground water may exceed 10 nephelometric turbidity units (NTU).

C. Advantages and Disadvantages of Low-Flow (Minimum Drawdown) Purging

In general, the advantages of low-flow purging include:
- samples which are representative of the mobile load of contaminants present (dissolved and colloid-associated);
- minimal disturbance of the sampling point thereby minimizing sampling artifacts;
- less operator variability, greater operator control;
• reduced stress on the formation (minimal drawdown);
• less mixing of stagnant casing water with formation water;
• reduced need for filtration and, therefore, less time required for sampling;
• smaller purging volume which decreases waste disposal costs and sampling time;
• better sample consistency; reduced artificial sample variability.

Some disadvantages of low-flow purging are:
• higher initial capital costs,
• greater set-up time in the field,
• need to transport additional equipment to and from the site,
• increased training needs,
• resistance to change on the part of sampling practitioners,
• concern that new data will indicate a change in conditions and trigger an action.

IV. Low-Flow (Minimal Drawdown) Sampling Protocols

The following ground-water sampling procedure has evolved over many years of experience in ground-water sampling for organic and inorganic compound determinations and as such summarizes the authors' (and others') experiences to date (Barcelona et al., 1984; 1994; Barcelona and Helfrich, 1986; Puls and Barcelona, 1989; Puls et. al. 1990, 1992; Puls and Powell, 1992; Puls and Paul, 1995). High-quality chemical data collection is essential in ground-water monitoring and site characterization. The primary limitations to the collection of representative ground-water samples include: mixing of the stagnant casing and fresh screen waters during insertion of the sampling device or ground-water level measurement device; disturbance and resuspension of settled solids at the bottom of the well when using high pumping rates or raising and lowering a pump or bailer; introduction of atmospheric gases or degassing from the water during sample handling and transfer, or inappropriate use of vacuum sampling device, etc.

A. Sampling Recommendations

Water samples should not be taken immediately following well development. Sufficient time should be allowed for the ground-water flow regime in the vicinity of the monitoring well to stabilize and to approach chemical equilibrium with the well construction materials. This lag time will depend on site conditions and methods of installation but often exceeds one week.

Well purging is nearly always necessary to obtain samples of water flowing through the geologic formations in the screened interval. Rather than using a general but arbitrary guideline of purging three casing volumes prior to sampling, it is recommended that an in-line water quality measurement device (e.g., flow-through cell) be used to establish the stabilization time for several parameters (e.g., pH, specific conductance, redox, dissolved oxygen, turbidity) on a well-specific basis. Data on pumping rate, drawdown, and volume required for parameter stabilization can be used as a guide for conducting subsequent sampling activities.

The following are recommendations to be considered before, during and after sampling:
• use low-flow rates (<0.5 L/min), during both purging and sampling to maintain minimal drawdown in the well;
• maximize tubing wall thickness, minimize tubing length;
• place the sampling device intake at the desired sampling point;
• minimize disturbances of the stagnant water column above the screened interval during water level measurement and sampling device insertion;
• make proper adjustments to stabilize the flow rate as soon as possible;
• monitor water quality indicators during purging;
• collect unfiltered samples to estimate contaminant loading and transport potential in the subsurface system.

B. Equipment Calibration

Prior to sampling, all sampling device and monitoring equipment should be calibrated according to manufacturer’s recommendations and the site Quality Assurance Project Plan (QAPP) and Field Sampling Plan (FSP). Calibration of pH should be performed with at least two buffers which bracket the expected range. Dissolved oxygen calibration must be corrected for local barometric pressure readings and elevation.

C. Water Level Measurement and Monitoring

It is recommended that a device be used which will least disturb the water surface in the casing. Well depth should be obtained from the well logs. Measuring to the bottom of the well casing will only cause resuspension of settled solids from the formation and require longer purging times for turbidity equilibration. Measure well depth after sampling is completed. The water level measurement should be taken from a permanent reference point which is surveyed relative to ground elevation.

D. Pump Type

The use of low-flow (e.g., 0.1-0.5 L/min) pumps is suggested for purging and sampling all types of analytes. All pumps have some limitation and these should be investigated with respect to application at a particular site. Bailers are inappropriate devices for low-flow sampling.
1) General Considerations

There are no unusual requirements for ground-water sampling devices when using low-flow, minimal drawdown techniques. The major concern is that the device give consistent results and minimal disturbance of the sample across a range of low flow rates (i.e., < 0.5 L/min). Clearly, pumping rates that cause minimal to no drawdown in one well could easily cause significant drawdown in another well finished in a less transmissive formation. In this sense, the pump should not cause undue pressure or temperature changes or physical disturbance on the water sample over a reasonable sampling range. Consistency in operation is critical to meet accuracy and precision goals.

2) Advantages and Disadvantages of Sampling Devices

A variety of sampling devices are available for low-flow (minimal drawdown) purging and sampling and include peristaltic pumps, bladder pumps, electrical submersible pumps, and gas-driven pumps. Devices which lend themselves to both dedication and consistent operation at definable low-flow rates are preferred. It is desirable that the pump be easily adjustable and operate reliably at these lower flow rates. The peristaltic pump is limited to shallow applications and can cause degassing resulting in alteration of pH, alkalinity, and some volatiles loss. Gas-driven pumps should be of a type that does not allow the gas to be in direct contact with the sampled fluid.

Clearly, bailers and other grab type samplers are ill-suited for low-flow sampling since they will cause repeated disturbance and mixing of stagnant water in the casing and the dynamic water in the screened interval. Similarly, the use of inertial lift foot-valve type samplers may cause too much disturbance at the point of sampling. Use of these devices also tends to introduce uncontrolled and unacceptable operator variability.

Summaries of advantages and disadvantages of various sampling devices are listed in Herzog et al. (1991), U.S. EPA (1992), Parker (1994) and Thurnblad (1994).

E. Pump Installation

Dedicated sampling devices (left in the well) capable of purging and sampling are preferred over any other type of device. Any portable sampling device should be slowly and carefully lowered to the middle of the screened interval or slightly above the middle (e.g., 1-1.5 m below the top of a 3 m screen). This is to minimize excessive mixing of the stagnant water in the casing above the screen with the screened interval zone water, and to minimize resuspension of solids which will have collected at the bottom of the well. These two disturbance effects have been shown to directly affect the time required for purging. There also appears to be a direct correlation between size of portable sampling devices relative to the well bore and resulting purge volumes and times. The key is to minimize disturbance of water and solids in the well casing.

F. Filtration

Decisions to filter samples should be dictated by sampling objectives rather than as a fix for poor sampling practices, and field-filtering of certain constituents should not be the default. Consideration should be given as to what the application of field-filtration is trying to accomplish. For assessment of truly dissolved (as opposed to operationally dissolved [i.e., samples filtered with 0.45 μm filters]) concentrations of major ions and trace metals, 0.1 μm filters are recommended although 0.45 μm filters are normally used for most regulatory programs. Alkalinity samples must also be filtered if significant particulate calcium carbonate is suspected, since this material is likely to impact alkalinity titration results (although filtration itself may alter the CO₂ composition of the sample and, therefore, affect the results).

Although filtration may be appropriate, filtration of a sample may cause a number of unintended changes to occur (e.g., oxidation, aeration) possibly leading to filtration-induced artifacts during sample analysis and uncertainty in the results. Some of these unintended changes may be unavoidable but the factors leading to them must be recognized. Deleterious effects can be minimized by consistent application of certain filtration guidelines. Guidelines should address selection of filter type, media, pore size, etc. in order to identify and minimize potential sources of uncertainty when filtering samples.

In-line filtration is recommended because it provides better consistency through less sample handling, and minimizes sample exposure to the atmosphere. In-line filters are available in both disposable (barrel filters) and non-disposable (in-line filter holder, flat membrane filters) formats and various filter pore sizes (0.1-5.0 μm). Disposable filter cartridges have the advantage of greater sediment handling capacity when compared to traditional membrane filters. Filters must be pre-rinsed following manufacturer’s recommendations. If there are no recommendations for rinsing, pass through a minimum of 1 L of ground water following purging and prior to sampling. Once filtration has begun, a filter cake may develop as particles larger than the pore size accumulate on the filter membrane. The result is that the effective pore diameter of the membrane is reduced and particles smaller than the stated pore size are excluded from the filtrate. Possible corrective measures include prefiltering (with larger pore size filters), minimizing particle loads to begin with, and reducing sample volume.

G. Monitoring of Water Level and Water Quality Indicator Parameters

Check water level periodically to monitor drawdown in the well as a guide to flow rate adjustment. The goal is minimal drawdown (<0.1 m) during purging. This goal may be difficult to achieve under some circumstances due to geologic heterogeneities within the screened interval, and may require adjustment based on site-specific conditions and personal experience. In-line water quality indicator parameters should be continuously monitored during purging. The water quality
indicator parameters monitored can include pH, redox potential, conductivity, dissolved oxygen (DO) and turbidity. The last three parameters are often most sensitive. Pumping rate, drawdown, and the time or volume required to obtain stabilization of parameter readings can be used as a future guide to purge the well. Measurements should be taken every three to five minutes if the above suggested rates are used. Stabilization is achieved after all parameters have stabilized for three successive readings. In lieu of measuring all five parameters, a minimum subset would include pH, conductivity, and turbidity or DO. Three successive readings should be within ± 0.1 for pH, ± 3% for conductivity, ± 10 mV for redox potential, and ± 10% for turbidity and DO. Stabilized purge indicator parameter trends are generally obvious and follow either an exponential or asymptotic change to stable values during purging. Dissolved oxygen and turbidity usually require the longest time for stabilization. The above stabilization guidelines are provided for rough estimates based on experience.

H. Sampling, Sample Containers, Preservation and Decontamination

Upon parameter stabilization, sampling can be initiated. If an in-line device is used to monitor water quality parameters, it should be disconnected or bypassed during sample collection. Sampling flow rate may remain at established purge rate or may be adjusted slightly to minimize aeration, bubble formation, turbulent filling of sample bottles, or loss of volatiles due to extended residence time in tubing. Typically, flow rates less than 0.5 L/min are appropriate. The same device should be used for sampling as was used for purging. Sampling should occur in a progression from least to most contaminated well, if this is known. Generally, volatile (e.g., solvents and fuel constituents) and gas sensitive (e.g., Fe**+, CH₄, H₂S/HS⁻, alkalinity) parameters should be sampled first. The sequence in which samples for most inorganic parameters are collected is immaterial unless filtered (dissolved) samples are desired. Filtering should be done last and in-line filters should be used as discussed above. During both well purging and sampling, proper protective clothing and equipment must be used based upon the type and level of contaminants present.

The appropriate sample container will be prepared in advance of actual sample collection for the analyses of interest and include sample preservative where necessary. Water samples should be collected directly into this container from the pump tubing.

Immediately after a sample bottle has been filled, it must be preserved as specified in the site (QAPP). Sample preservation requirements are based on the analyses being performed (use site QAPP, FSP, RCRA guidance document [U. S. EPA, 1992] or EPA SW-846 [U. S. EPA, 1982]). It may be advisable to add preservatives to sample bottles in a controlled settling prior to entering the field in order to reduce the chances of improperly preserving sample bottles or introducing field contaminants into a sample bottle while adding the preservatives.

The preservatives should be transferred from the chemical bottle to the sample container using a disposable polyethylene pipet and the disposable pipet should be used only once and then discarded.

After a sample container has been filled with ground water, a Teflon™ (or tin)-lined cap is screwed on tightly to prevent the container from leaking. A sample label is filled out as specified in the FSP. The samples should be stored inverted at 4°C.

Specific decontamination protocols for sampling devices are dependent to some extent on the type of device used and the type of contaminants encountered. Refer to the site QAPP and FSP for specific requirements.

I. Blanks

The following blanks should be collected:

1. field blank: one field blank should be collected from each source water (distilled/deionized water) used for sampling equipment decontamination or for assisting well development procedures.

2. equipment blank: one equipment blank should be taken prior to the commencement of field work, from each set of sampling equipment to be used for that day. Refer to site QAPP or FSP for specific requirements.

3. trip blank: a trip blank is required to accompany each volatile sample shipment. These blanks are prepared in the laboratory by filling a 40-mL volatile organic analysis (VOA) bottle with distilled/deionized water.

V. Low-Permeability Formations and Fractured Rock

The overall sampling program goals or sampling objectives will drive how the sampling points are located, installed, and choice of sampling device. Likewise, site-specific hydrogeologic factors will affect these decisions. Sites with very low permeability formations or fractures causing discrete flow channels may require a unique monitoring approach. Unlike water supply wells, wells installed for ground-water quality assessment and restoration programs are often installed in low water-yielding settings (e.g., clays, silts). Alternative types of sampling points and sampling methods are often needed in these types of environments, because low-permeability settings may require extremely low-flow purging (<0.1 L/min) and may be technology-limited. Where devices are not readily available to pump at such low flow rates, the primary consideration is to avoid dewatering of
the well screen. This may require repeated recovery of the water during purging while leaving the pump in place within the well screen.

Use of low-flow techniques may be impractical in these settings, depending upon the water recharge rates. The sampler and the end-user of data collected from such wells need to understand the limitations of the data collected; i.e., a strong potential for underestimation of actual contaminant concentrations for volatile organics, potential false negatives for filtered metals and potential false positives for unfiltered metals. It is suggested that comparisons be made between samples recovered using low-flow purging techniques and samples recovered using passive sampling techniques (i.e., two sets of samples). Passive sample collection would essentially entail acquisition of the sample with no or very little purging using a dedicated sampling system installed within the screened interval or a passive sample collection device.

A. Low-Permeability Formations (<0.1 L/min recharge)

1. Low-Flow Purging and Sampling with Pumps

a. "portable or non-dedicated mode" - Lower the pump (one capable of pumping at <0.1 L/min) to mid-screen or slightly above and set in place for minimum of 48 hours (to lessen purge volume requirements). After 48 hours, use procedures listed in Part IV above regarding monitoring water quality parameters for stabilization, etc., but do not dewater the screen. If excessive drawdown and slow recovery is a problem, then alternate approaches such as those listed below may be better.

b. "dedicated mode" - Set the pump as above at least a week prior to sampling; that is, operate in a dedicated pump mode. With this approach significant reductions in purge volume should be realized. Water quality parameters should stabilize quite rapidly due to less disturbance of the sampling zone.

2. Passive Sample Collection

Passive sampling collection requires insertion of the device into the screened interval for a sufficient time period to allow flow and sample equilibration before extraction for analysis. Conceptually, the extraction of water from low yielding formations seems more akin to the collection of water from the unsaturated zone and passive sampling techniques may be more appropriate in terms of obtaining "representative" samples. Satisfying usual sample volume requirements is typically a problem with this approach and some latitude will be needed on the part of regulatory entities to achieve sampling objectives.

B. Fractured Rock

In fractured rock formations, a low-flow to zero purging approach using pumps in conjunction with packers to isolate the sampling zone in the borehole is suggested. Passive multi-layer sampling devices may also provide the most "representative" samples. It is imperative in these settings to identify flow paths or water-producing fractures prior to sampling using tools such as borehole flowmeters and/or other geophysical tools.

After identification of water-bearing fractures, install packer(s) and pump assembly for sample collection using low-flow sampling in "dedicated mode" or use a passive sampling device which can isolate the identified water-bearing fractures.

VI. Documentation

The usual practices for documenting the sampling event should be used for low-flow purging and sampling techniques. This should include, at a minimum: information on the conduct of purging operations (flow-rate, drawdown, water-quality parameter values, volumes extracted and times for measurements), field instrument calibration data, water sampling forms and chain of custody forms. See Figures 2 and 3 and "Ground Water Sampling Workshop -- A Workshop Summary" (U. S. EPA, 1995) for example forms and other documentation suggestions and information. This information coupled with laboratory analytical data and validation data are needed to judge the "useability" of the sampling data.

VII. Notice

The U.S. Environmental Protection Agency through its Office of Research and Development funded and managed the research described herein as part of its in-house research program and under Contract No. 68-C4-0031 to Dynamac Corporation. It has been subjected to the Agency's peer and administrative review and has been approved for publication as an EPA document. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

VIII. References


## Figure 2. Ground Water Sampling Log

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<th>Well No.</th>
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<td>Well Diameter</td>
<td>Casing Type</td>
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<td>Tubing type</td>
<td>Water Level</td>
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<td>Measuring Point</td>
<td>Other Info</td>
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**Sampling Personnel**

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</table>

**Type of Samples Collected**

Information: 2 in = 617 ml/ft, 4 in = 2470 ml/ft: \( V_{cyl} = \pi r^2 h \), \( V_{sphere} = \frac{4}{3} \pi r^3 \)
Figure 3. **Ground Water Sampling Log** (with automatic data logging for most water quality parameters)

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<th>Date</th>
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**Type of Samples Collected**

Information: 2 in = 617 ml/ft, 4 in = 2470 ml/ft; $V_{vol} = n^2 h$, $V_{sphere} = 4/3 \pi r^3$
### Project Information
- **Project Name:**
- **AECOM Project Number:**

### Sampling Information
- **Field Team:**
- **Purge Method:**
- **Pump Intake Depth (ft btc):**
- **Flow-Through Cell:**
- **Sampling Method:**
- **Decontamination Method:**
- **Purge Water Disposition:**
- **Field Conditions:**

### Comments:

### Well Information

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<th>Screen Interval (ft bgs)</th>
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<th>Water Column (ft)</th>
<th>Convert Factor (gal/ft)</th>
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<th>Three Well Volumes (gal)</th>
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3/4"=0.023 gal/ft    2"=0.17 gal/ft    4"=0.66 gal/ft    6"=1.5 gal/ft

### Sample Containers

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### Well Purge Data

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<th>ORP (mV)</th>
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### Total Volume to Purge (gal) =

#### Note:
- bgs= below ground surface
- btc=below top of casing
- DTW=depth to water
- Clarity: VC=very cloudy      Cl=cloudy      SC=slightly cloudy      AC=almost clear      C=clear      CC=crystal clear

### File:
Form 1_MW sample form (Updated: 05/10/05) AECOM
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**River Stage** (download data from PLC river transducer and record the nearest hourly readings)

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- **WIV** = Water in Vault/Monument
- **COP** = City of Portland vertical datum
- **TFP** = Total Fluids Pump
- **BTC** = Below Top of Casing
- **GWL** = GW/LPH Monitoring
- **System Wells**
- **BP Terminal 22T**
- **O:38478328 BP 22T\Up\land\G\M\5000_Technical\GW\Sampling\SAP\Appendix B Field Forms\Form-2_Water-Product Level Field Forms (updated 20150521); System Wells

*Measure all wells within 4 hours of first measurement collected

Tide: High / Low

_Copyright © 2015 URS Corporation_
### Well Data Collection Form

**GW/LPH Monitoring**

**Monitoring Wells**

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<th>Time Measured</th>
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<th>Depth to Water feet (btc)</th>
<th>Product Thickness feet</th>
<th>GW Sampling Well <strong>see note</strong></th>
<th>Notes</th>
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btc = below top of casing

**see note**

** = If well selected for GW sampling and product is detected, notify PM.
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<th>Depth to Product feet (btc)</th>
<th>Depth to Water feet (btc)</th>
<th>Product Thickness feet (if present)</th>
<th>Pump Type</th>
<th>Notes</th>
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btc = below top of casing
** = If product is detected, notify PM.
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bgs = below ground surface  
btc = below top of casing  
B = Blue Solinst meter  
R = Red Solinst meter
## Well Data Collection Form

**GW/LPH Monitoring**

### MD Wells

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- **Was the well under pressure when opened? Indicate using:**
  - P- well is under pressure
  - V- well is under vacuum
  - NA- well is under neither pressure nor vacuum

- **Notes:**
  - Site closes at 3 pm.

- **Site:**
  - BTC = below top of casing
  - * = if product is detected, notify M. Mudge.

---

*BP Terminal 22T*

930 NW St. Helens Road

Portland, OR

Project # 38476326

URS Corporation

O:\38476326 BP 22T\upblend\06\865000-Tech\02\GW Sampling\SAP\Appendix B Field Forms\Form-2_Water-Product Level Field Forms (updated 2/15/2015) MD Wells*