L-Bar Site
Compliance Monitoring Program
Sampling and Analysis Work Plan
2020 Revision

Prepared for

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Acronyms/Abbreviations

CAP	Cleanup Action Plan
CH2M HILL	CH2M HILL Engineers, Inc.
CMP	Compliance Monitoring Program
Ecology	Washington State Department of Ecology
FD	Field Duplicate
FS	Feasibility Study
HDPE	High Density Polyethylene
Mag. Pile	Magnesite Residue Pile
MRL	Method Reporting Limit
MS/MSD	Matrix Spike/Matrix Spike Duplicate
MTCA	Model Toxics Control Act
NPDES	National Pollutant Discharge Elimination System
PW	Production Well
QA	Quality Assessment
QC	Quality Control
RA	Risk Assessment
RI	Remedial Investigation
RPD	Relative Percent Difference
RSD	Relative Standard Deviation
SCCD	Stevens County Conservation District
SOPs	Standard Operating Procedures
SRM	Standard Reference Material
SWBU	Shallow
TDS	Total dissolved solids
TMDLs	Total Maximum Daily Loads
WAC	Washington Administrative Code

1. Introduction

The Final Cleanup Action Plan (CAP) for the L-Bar Site, prepared by the Washington State Department of Ecology (Ecology), identifies Source Removal with Natural Attenuation and Monitoring (Alternative 2) as the selected cleanup action for the L-Bar Site (Ecology, 2000). Section 8.4 of the Cleanup Action Plan describes the requirements for developing a Compliance Monitoring Plan (CMP) for the L-Bar Site.

This CMP includes a description of performance and confirmation monitoring (termed herein *compliance monitoring*) along with the analytical requirements to support the cleanup and monitoring objectives of the L-Bar cleanup actions completed in 2003. Compliance monitoring conducted under Agreed Order No. DE 00TCPER-984 will build upon and extend the site-wide monitoring performed during both the Phase I Remedial Investigation and various post-RI Interim Action activities. Previous monitoring performed under Agreed Order No. DE 94TC-E104 was conducted between June 1995 and June 2000. These existing data—especially the groundwater quality data—serve as statistically representative baseline conditions to assess the effectiveness of the selected remedy as future data are collected and evaluated. Given that the source removal actions were completed by roughly 2004, and that the CAP specifies a restoration timeframe of 20 to 30 years, the CMP is anticipated to be active for at least another four to 14 years (through 2024 to 2034) to track progress toward achievement of the cleanup goals.

1.1 Purpose and Objectives

In 2018, Alcoa submitted the 2017 L-Bar Site Compliance Monitoring Program Data Summary Report and Five-Year Review (CH2M HILL, 2018). Upon review, Ecology finalized their assessment of site conditions and recommendations in the *Second Period Review, L-Bar Site* (Periodic Review) (Ecology, 2019). Based on the recommendations within the Periodic Review, the 2012 Compliance Monitoring Program Sampling and Analysis Work Plan Addendum No. 1 (CH2M HILL, 2012) has been updated (revised) with the recommendations presented in the Periodic Review.

The purpose of the CMP is to describe the current site-wide monitoring activities, sampling procedures, quality control, and reporting requirements for shallow groundwater and surface water data collected at the L-Bar site. This revised CMP is a stand-alone document that supersedes the original CMP (and the subsequent 2012 CMP Addendum 1 (CH2M HILL, 2012)) presented in Section 3 of the *L-Bar Material Removal and Compliance Monitoring Work Plan* (CH2M HILL, 2001a) and follows the requirements outlined in the Agreed Order No. DE 00TCPER-984. Data generated under the CMP will be used to demonstrate the effectiveness of the source removal actions and natural attenuation processes for achieving compliance with applicable cleanup levels and standards.

In accordance with the requirements of Washington Administrative Code (WAC) 173-340-410, the L-Bar CMP includes three separate but interrelated monitoring objectives:

(1) Confirm that human health and the environment are adequately protected during implementation of the cleanup action (*protection monitoring*);

(2) Confirm that the cleanup action has attained cleanup standards and, if appropriate, other performance standards (*performance monitoring*);

(3) Confirm the long-term effectiveness of the cleanup action once cleanup standards (and, if appropriate, other performance standards) have been met (*confirmation monitoring*).

1.2 Project Organization

Appendix A lists the project organization and key points-of-contact for the L-Bar CMP. In accordance with Model Toxics Control Act (MTCA) cleanup actions, Ecology's designated Site Manager ensures that cleanup actions and associated site monitoring are conducted in accordance with the CAP (Ecology, 2000). Ecology's Site Manager reviews data reports and performs periodic site reviews to ensure that site activities and monitoring are conducted in accordance with MTCA requirements and associated decision documents.

The L-Bar property was sold by Northwest Alloys to a private entity in 2005; however, Northwest Alloys maintains access rights and remains the responsible party to ensure that monitoring and reporting are being performed in accordance with MTCA cleanup requirements, and as described in this CMP. Northwest Alloys administers the financial aspects of the site cleanup and associated monitoring activities. Under the direction of and by contractual agreement with Northwest Alloys, the technical aspects of the site monitoring and reporting activities are performed by designated entities (currently, a collaborative effort with NWA's contract environmental consulting firm and Stevens County Conservation District [SCCD]). NWA's contractor conducts the groundwater sampling, site-wide data management, and reporting. SCCD conducts the surface water sampling and provides annual submittals of surface water data.

1.3 Site Description

1.3.1 Site Setting and Property Ownership

The L-Bar site is located approximately 2 miles south of Chewelah, Washington, on the east side of US Hwy 395, as shown in Figure 1. The site occupies approximately 67 acres of industrial and agricultural land in the Colville River Valley. The site is bordered by agriculture parcels to the north, east, and west, and by an active aggregate supply operation immediately south along Logan Road. Major existing site features include miscellaneous plant buildings and storage warehouse; two high density polyethylene (HDPE)-lined ponds (Evaporation Pond and Storm water Holding Pond); a sanitary lagoon; and a large, magnesite residue pile that covers much of the southwest portion of the site. The Colville River passes along the northern margins of the site, and a Burlington–Northern railroad line is located on the eastern edge of the site.

This site was been owned by many entities prior to Northwest Alloys. In late 2005, NW alloys sold the facility to a private entity (the Ernie Smith Trust). As part of the sales agreement, Northwest Alloys and its representatives retain access rights to the facility for the purposes of groundwater and surface water monitoring in support of MTCA cleanup activities.

Since approximately 2016, a marijuana grow facility (grow operation) has been operating on a portion of the L-Bar site in the mostly paved area directly east of the magnesite residue piles. The grow operation installed a perimeter consisting of existing buildings, fencing, and conex container boxes that prevent access to the grow operations within. The perimeter of the grow operation stretches from just south of the well P-09, north over the former covered flux bar residue pile, and to the east to the site boundary. The west side of the grow operation abuts the toe of the magnesite residue pile. L-bar monitoring well P-09 and production well PW are located within the secured grow operation facility and are accessed via coordination with the grow operation staff.

1.3.2 Remedial Actions/Source-Removal Activities

Table 1 is a timeline of significant site activities (including remedial actions (RAs)/source removal actions) at the L-Bar site from 1996 through 2020. The primary RAs/source removal activities included the following (as shown in Figure 1):

- removal of Flux Bar and Flux Bar Residue piles from atop the Magnesite Residue Pile (hereafter, "Mag. Pile") from May 1997 through December 1999;
- removal of the Covered Flux Bar Residue Pile (hereafter, "Covered Pile") and source materials stored in onsite plant buildings between July 2000 and February 2004;
- closure of the Main Ditch and removal of the HPDE (high-density polyethylene) barrier wall along the western and northern perimeter of the Covered Pile in the summer of 2003.

The primary objective of the CMP is to evaluate changes in the surface water and shallow groundwater in response to the prior RAs conducted from approximately 1999 to 2004. Additional details of these and other RAs were documented in two previous reports and are not reiterated herein: the *Interim Action Source Removal Summary Report–Magnesite Residue Pile, L-Bar Site* (CH2M HILL, 2001b), and the *Source Removal Summary Report–Covered Pile and Plant Buildings, L-Bar Site* (CH2M HILL, 2004).

1.4 Legal Requirements for Monitoring

Releases of hazardous substances to onsite environmental media prompted Ecology to require that site investigation and cleanup actions be undertaken at the L-Bar site pursuant to MTCA (WAC, Chapter 173-340). In 1994, Ecology issued an enforcement order requiring Northwest Alloys to control discharge of contaminated water from an onsite ditch (West Ditch) to the Colville River. In conformance with the requirements of the Agreed Order (DE 94TC-E104), Northwest Alloys completed a remedial investigation (RI) of the facility and completed a site-wide risk assessment.

The RI determined the nature and extent of the chemicals of interest present at the L-Bar site. The RI report was submitted to Ecology in August 1998, which documented investigation activities performed from 1995 to 1996. Public review and comment on the RI document were completed October 22, 1998. Results of the RI are presented in the *L-Bar Phase I Remedial Investigation Report* (CH2M HILL, 1998).

In accordance with the Agreed Order requirements, results from the RI and a site-specific risk assessment served as the technical basis for selecting a site-wide cleanup remedy that effectively mitigates chemical impacts to site media (i.e., surface water and groundwater). Information from the RI, MTCA pilot studies, interim actions, and the risk assessment were used in the feasibility study (FS) process to screen remedial technologies and RA alternatives. Results from the FS are detailed in a report titled *L-Bar Cleanup Levels Development and Feasibility Study Report* (CH2M HILL, 1999).

As described in the FS report and accepted by Ecology, Northwest Alloys recommended Alternative 2 (Source Removal with Natural Attenuation and Monitoring) as the preferred cleanup action for the L-Bar site. Groundwater cleanup levels for the L-Bar site were also developed in the *L-Bar Cleanup Levels Development and Feasibility Study Report* (CH2M HILL, 1999); the analyte specific groundwater cleanup levels are presented in Section 4. Pursuant to the cleanup actions recommended in the FS, source removal activities were guided by the *L-Bar Material Removal and Compliance Monitoring Work Plan* (CH2M HILL, 2001a).

1.5 Data Quality Objectives

The data quality objectives of the CMP are to develop and implement procedures that will provide data of known and appropriate quality to facilitate site decisions. Data collected under the CMP will be compared to the historical site monitoring data (collected from June 1995 and June 2000), which will serve as a comparative baseline. The primary objective is to assess the effectiveness of the source removal activities and natural attenuation processes for cleanup of shallow groundwater. Data generated during the compliance monitoring period will require standard levels of quality assurance (QA). Data will be of sufficient quality and quantity to support the evaluation of changes in the indicator substance concentrations that result from source removal and natural attenuation. Field sampling and monitoring, laboratory analysis, and data validation will be performed to meet those needs.

Primarily two types of data, with correspondingly different levels of data quality, will be generated as part of the CMP:

- Validated laboratory analysis data
- Non-validated field measurements

Appendix B contains the data uses and data quality objectives for surface water (Table B-1) and groundwater (Table B-2). The data uses and data quality objectives for the CMP were established previously in Appendix E of the *L-Bar Material Removal and Compliance Monitoring Work Plan*, dated January 2001. Specific data quality objectives (DQOs) for each of the analytical parameters were selected through consideration of specific data uses, cleanup levels, site decisions, users, and regulatory requirements. The rationale for the selection and usage of the analytical parameters is described in detail in Section 3 of the *L-Bar Material Removal and Compliance Monitoring Work Plan* (CH2M HILL, 2001a). The methods in Appendix B represent the current analytical methods for each of the parameters.

Quality assurance objectives, including the analytical accuracy, precision, and completeness targets for surface water (Table B-3) and groundwater (Table B-4) analyses are also included in Appendix B. Data quality may be quantified by representativeness, comparability, accuracy, precision, and completeness. Definitions of these parameters and the applicable procedures to evaluate data quality are described in Section 4.2.

2. Compliance Monitoring Plan

This section describes the current monitoring activities for the CMP at the L-Bar site.

2.1 Overview of Monitoring Program

From 2001 to 2006, the CMP included two monitoring programs: (1) the CMP, and (2) Pollutant Discharge Elimination System (NPDES) substantive-requirements monitoring. These two programs were implemented to satisfy separate but overlapping monitoring requirements with respect to surface water and groundwater quality conditions at both the L-Bar site and along an adjacent reach of the Colville River.

In 2006, Ecology conducted an independent evaluation of surface water quality data from the L-Bar site with respect to the NPDES substantive-requirements monitoring program. The NPDES substantive-requirements monitoring program provided water quality data for an approximately 8-mile long reach of the Colville River to support Ecology's efforts to establish total maximum daily loads (TMDLs) for the river. The NPDES substantive-requirements monitoring program included Colville River surface water, L-Bar surface water (West Ditch), and shallow L-Bar site groundwater collected from three monitoring wells (P-05, P-19, and P-20B) located near the river. As documented in Ecology's report titled *Surface Water Data Review, L-Bar Site, June 2006 (Section 7.0),* Ecology determined that "there is no need to continue monitoring the West Ditch discharge and the Colville River for compliance with the NPDES discharge limits." In response, Northwest Alloys discontinued NPDES discharge-limit monitoring, with the final such monitoring occurring in April 2006.

Routine monitoring in support of this revised CMP will continue into the foreseeable future as described in the sections that follow. Routine monitoring of shallow groundwater and surface water at the L-Bar site provides a direct indication of the effectiveness of the selected cleanup remedy and the degree to which measured concentrations of indicator constituents are approaching their respective cleanup levels. The CMP addresses several monitoring requirements and objectives, and are developed to:

- satisfy regulatory monitoring requirements;
- demonstrate water quality changes attributable to source removal activities;
- evaluate the ongoing effectiveness of natural attenuation processes for selected L-Bar indicator constituents;
- assess both seasonal and long-term changes in groundwater and surface water quality.

2.2 Surface Water Sampling Procedures

This section provides a description of the surface water monitoring performed under the CMP.

2.2.1 Surface Water Stations and Sampling Frequency

Surface water samples historically were collected from a series of eleven monitoring stations that were established to support the two overlapping monitoring programs and objectives (described in Section 2.1). In the fall of 2003, the Main Ditch was closed, eliminating monitoring station D1. As described earlier, the NPDES substantive-requirements monitoring program was terminated in June 2006, eliminating six more surface water monitoring stations. Thus, a total of four surface water monitoring stations remain as part of the current CMP as listed below (also shown in Figure 1 and listed in Table 2.1):

- Station D3 – upstream in the West Ditch (upstream of station D2)
- Station D2 – mouth of the West Ditch (direct discharge to Colville River)
- Station CR1 – Colville River at the Hwy 395 Bridge (upstream of the West Ditch mouth)
- Station CR3 – Colville River (~ 300 feet downstream from the West Ditch mouth)

Surface water sampling is performed semi-annually (twice per year) at these four stations. Samples are collected during high surface water flow in the spring (typically in May or early June) and during low surface water flow in the fall (typically in October and when a surface water discharge of at least 10 gallons/minute is present at West Ditch station D2). Surface water sampling events are coordinated to occur during a common timeframe with groundwater sampling (described in next section) to bracket the seasonal variability. During low surface water flow, the relative contribution of groundwater to surface water is greatest, and as such, this period is the most conservative (worst-case) hydrologic condition to assess potential groundwater impacts (flux of contaminants) to the Colville River reach adjacent to the site.

2.2.2 Surface Water Analytical Suite, Sampling, and Field Measurements

This section summarizes the surface water field and laboratory analytical parameters, methods, and Method Reporting Limits (MRLs).

Surface Water Analytical Suite and Sampling Procedures

Table 2-1 shows the surface water analytical suite, which includes ammonia and chloride. Surface water quality samples will be collected at each station during each sampling event (described above). The sampling sequence for a given event will consist of monitoring downstream stations first and progressing to upstream stations to minimize stream disturbance impacts during sampling.

Depending on the sampling location or the hydrologic event, surface water quality samples will be collected using either *Equal Width Increment* (EWI) or 'grab' sample methods as summarized in Table 2-2.

Grab samples will be collected at the West Ditch stations (D3 and D2) during all sampling events given the limited channel size/configuration and in consideration of the weir structure at D2 (which facilitates a representative and well mixed sample at this station). Grab samples will be collected during the high-flow events at the Colville River stations given that it is unsafe to enter the stream under these conditions to perform EWI sampling. Grab samples collected at the Colville River stations target the mid-channel width and depth.

The EWI method is considered the most representative sampling method and will be used at the Colville River stations CR1 and CR3 when the flow conditions are suitable to facilitate in-stream sampling (i.e., low-flow period). As noted above, the fall low-flow period is the most conservative hydrologic condition to assess potential groundwater impacts to the Colville River reach adjacent to the site. The EWI method is described in the *National Field Manual for the Collection of Water Quality Data*, Book 9, Chapter 4, Technical Water Resource Investigations (USGS, 1999). The EWI method is included in Appendix C.1 and summarized below.

Surface water quality sampling procedures per the EWI method include the following key steps—as summarized from Appendix C.1:

1. The non-metallic sampler and churn sample splitter (temporary sampling container/mixer) will be decontaminated (using procedures listed in Section 3.5) and rinsed in the stream to be sampled, prior to sampling.
2. The width of the stream will be determined by stringing a measuring tape across the stream perpendicular to the flow (referred to as a "transect").
3. Samples will be collected at each of 10 equal-width sampling increments established along the transect. The stream width will be divided by the number of verticals (ten) to obtain the sampling increments along the transect.
4. Surface water samples will then be collected at the center of each vertical increment with the sampler pointing upstream. The rate (i.e., transit rate) at which the sampler is lowered and raised must be nearly identical at each vertical increment. By using an equal transit rate, a volume of water collected will be proportional to the flow. During sample collection, the person sampling should stand downstream so as to not impact the water being sampled.
5. When sampling is complete at each interval or when the sampler is full, the contents will be transferred into a churn sample splitter (or equivalent sampling/mixing container).
6. Each sample location and the volume of sample collected at each vertical increment will be recorded.
7. When all vertical increments have been sampled and all sample volume transferred to the churn sample splitter, the sample will be transferred into the sample containers. The composited sample will be churned during all sample transfers. For filtered samples, the sample will be pumped from the churn sample splitter spigot using a peristaltic pump and inline filter. For non-filtered samples, the sample container will be filled directly from the churn sample splitter spigot.

Immediately following collection of the surface water quality sample, surface water field measurements will be collected at the same transect location (as described in the following section).

Field Measurements and Procedures

Table 2-1 shows the surface water field measurements, which include discharge, temperature, pH, and specific conductance. Dissolved oxygen, though not a required, is also measured at Stations CR1 and CR3. Field measurements are collected at each station immediately following collection of the water quality sample. Surface water field parameters will be collected at the same transect location as the water quality sample. Field parameters will be measured using a multi-parameter handheld meter (YSI Pro 1030 or equivalent) and recorded on field forms. Equipment used to measure field parameters will be maintained and calibrated according to manufacturer's specifications. At a minimum, calibration will occur at the start of each day and will be documented in the field logbook along with the equipment serial number.

Field procedures for discharge measurements at Colville River stations (CR1 and CR3) follow the methods for *Standard Operating Procedures for Estimating Streamflow, EAP 024* (Ecology, 2007). During high-flow conditions the channel is unsafe to enter at downstream station CR3; under these conditions the flow for CR3 is estimated as the sum of flow at stations CR1 and D2. Discharge measurements in the West Ditch at stations D2 and D3 are collected using a bucket and stopwatch method given the limited channel size and relatively low-flow conditions. A weir has been constructed to enhance collection of water quality and discharge measurements at the mouth of West Ditch (station D2). Conditions at the upstream West Ditch (station D3) are often stagnant or frozen, which precludes a discharge reading.

Discharge measurements at Colville River stations (CR1 during both high and low flow, and for CR3 during low flow only) include the following key steps as summarized in Appendix C.2):

1. An engineering tape (graduated in tenths of feet) will be strung across the stream channel (referred to as a "transect") perpendicular to the flow direction at the established surface water monitoring stations. The established transect location and orientation of engineering tape across channel will remain consistent between monitoring events.

2. The distance from the initial point of measurement to the edge of water will be recorded (i.e., left edge or right edge facing downstream). The depth at the edge of water will be recorded. The edge of water opposite the initial point will be recorded to determine the span of the channel for a given monitoring event.

3. Discharge measurements will be recorded in feet/sec at 0.5-foot increments across the channel using a Marsh-McBirney Model 2000 meter (or equivalent) from the edge of water near the initial point of measurement.

4. The distance along the measuring tape (recorded in tenths of feet), stream depth (tenths of feet), and stream flow velocity (ft/sec) will be recorded at each increment.

5. The wading rod should be held in a vertical position with the meter parallel to the direction of flow during measurement.

Under high-flow conditions, discharge measurements for upstream station CR1 may be performed safely as described above from the nearby US-395 bridge structure. There are not any existing structures at the downstream station CR3 to facilitate in-stream methods, so as noted above, under high-flow conditions the discharge for station CR3 is estimated as the sum of discharge at stations CR1 (upstream) and D2 (mouth of West Ditch).

Surface Water Field and Laboratory Quality Control Sample Collection

Quality Control (QC) samples will be collected to assist in determining data quality and reliability. QC surface water samples include field duplicates and temperature blanks. QC field duplicate (FD) samples are normally collected from locations that are suspected to be of moderate contamination (such as stations D2 or CR3). QC samples will be collected using the same procedures and immediately following collection of the target or "normal" sample. QC sample assessment is described in Section 4.2.

Field duplicate (FD) samples will be collected at a minimum frequency of **one FD per sampling event**. A FD is an independent sample collected as close as possible to the original sample from the same source and is used to assess sampling precision. FDs will be labeled and packaged in the same manner as normal samples so that the laboratory cannot distinguish between normal samples and duplicates. Each FD will be taken using the same sampling and preservation method as other samples.

Temperature blanks provide a means of verifying that samples have been maintained at the proper temperature (4 °C) following collection and during transport to the laboratory. **One temperature blank will be included with each cooler shipment** containing samples (regardless of targeted analysis) sent to the laboratory. A temperature blank consists of a sample vial filled in the field with de-ionized water, handled like an environmental sample, and returned to the laboratory with the samples for analysis.

2.3 Groundwater Sampling Procedures

This section provides a description of the groundwater monitoring under the CMP.

2.3.1 Groundwater Monitoring Well Network and Sampling Frequency

The current CMP well network consists of 12 groundwater monitoring wells installed to monitor the shallow water bearing unit at the site, and 1 groundwater production well (PW) that obtains groundwater from a deeper, confined, alluvial water-bearing zone. Figure 1 shows the well locations. Table 3 presents the construction and lithologic details for the monitoring network. The wells are grouped into the following four categories based upon their location and hydraulic gradient:

- Site Background: P-12 and the Production Well (PW) [Upgradient]
- Site Interior: P-09 and P-13 [Mid-gradient]
- Magnesite Residue Pile: SA-10, SA-11, SA-14 [Mid-gradient]
- North of Site: P-05, P-06, P-19, P-20B, P-25, and P-27 [Downgradient]

Groundwater sampling is performed semi-annually (twice per year) at these 13 locations, including 12 shallow resource protection monitoring wells and the one deep PW. Groundwater sampling is performed during the seasonal high Colville River stage (typically in May or early June) and seasonal low Colville River stage (typically in October to Mid-November). The groundwater quality parameters are described in the next section. Groundwater sampling events are coordinated with and sampled during a common timeframe with the surface water sampling (described in prior section) to bracket the seasonal variability.

2.3.2 Groundwater Analytical Suite and Field Procedures

This section describes the analytical suite, field parameters, and procedures for groundwater sampling.

Groundwater Analytical Suite

Table 4 summarizes the groundwater monitoring network, analytical suite, methods, and laboratory reporting limits. As shown in Table 4, the groundwater monitoring suite has been grouped into primary indicator parameters (ammonia, chloride, and total dissolved solids [TDS]) and secondary parameters (nitrate, nitrite, barium, manganese, selenium, thallium and turbidity). These two groupings have been established in this revised CMP to facilitate a revised sampling frequency respective of the groupings. The primary indicator parameters are sampled yearly at a semi-annual frequency, and the secondary parameters are sampled semi-annually, every other year (typically during even numbered years).

The primary and secondary groups and their monitoring frequencies in this revised CMP has been established in recognition that the concentrations of the primary parameters are generally more elevated in comparison to the secondary parameters, as demonstrated in the *L-Bar Site Compliance Monitoring and Data Evaluation Report, 1996-2010* (CH2M HILL 2011). As such, results from the primary list of constituents will be the primary emphasis of future data evaluation reports to evaluate remedy performance, yet still retaining the entire suite of CMP parameters to evaluate progress toward established cleanup levels. This revised sampling frequency for the primary and secondary parameter groupings was acceptable to Ecology based on their *Periodic Review* of the L-Bar Site (Ecology 2012).

To minimize the potential for cross-contamination, the groundwater sampling sequence will progress from upgradient to downgradient locations as follows: site background, site interior, north of site, and magnesite residue pile (most impacted wells).

Groundwater Field Measurements and Sampling Procedures

Nine of the twelve monitoring wells (excluding the three SA wells) are purged and sampled with a peristaltic pump, using low-flow purging techniques consistent with the methodologies and procedures described in *Ground-Water Sampling Guidelines for Superfund and RCRA Project Managers* (EPA, 2002a). A detailed description of the low-flow method is included in Appendix D. Dedicated tubing is assigned to each well. Prior to sampling, each monitoring well is purged at a rate approximately equal to the recharge rate for that well, typically ranging from about 100 to 600 mL/min. Dedicated single-stage, single-speed submersible pumps with dedicated tubing are used to sample each of the three deeper wells located on top of the Magnesite Residue Pile (SA-10, SA-11, and SA-14). Due to design limitations of the pump, the SA wells are purged at a rate of approximately 1 to 3 gallons per minute.

Upon arrival at each well, the wellhead shall be inspected to verify that the cap and protective monument are intact and in proper working order. Potential problems with the well cap, protective monument, or well seal shall be communicated to Northwest Alloys and its contract project manager. Prior to purging and sampling activities, the static depth to water shall be recorded to the nearest hundredth foot. This initial measurement shall be recorded on the field forms and reported as the “static” level (converted to groundwater elevation) for the respective sampling event. The well sounder shall be decontaminated before initial use and between each successive well location (using the procedures described in Section 3.5).

During the purging cycle, field parameters listed in Table 5 (pH, specific conductance, temperature and water-level) are measured and recorded at 5-minute intervals, and groundwater samples are collected when the pH stabilizes to within ±0.1 and specific conductance stabilizes to within +/-3 percent. Groundwater samples are collected directly from the peristaltic pump or submersible pump discharge tubing into laboratory-supplied sample containers.

The PW (as well as well P-09) is located within the secured perimeter of the grow operation and requires coordination with site personnel to access and sample. The PW is located within a small well house and is operating nearly continuously to support the grow operations at the site and is sampled from a sample port controlled by a valve. Due to continual operation of the pump, only minimal purging is necessary for sample collection (typically 1 to 2 gallons). Once field parameters are collected, sample containers are filled directly from the sample port.

Equipment used to measure field parameters will be maintained and calibrated according to manufacturer’s specifications. At a minimum, calibration will occur at the start of each sampling day and will be documented in the field logbook along with the equipment/meter model number and serial number.

Groundwater Field and Laboratory Quality Control Sample Collection

QC samples will be collected to assist in determining data quality and reliability. QC samples include field duplicates (FD), blank samples, and laboratory QC samples (for matrix spike [MS] and matrix spike duplicate [MSD] analyses). Field duplicate samples are normally collected from locations that have previously had moderate contamination (typically from the north field or SA wells). Other QC samples will be collected from wells based on field judgment. All QC samples will be collected using the same procedures and immediately following collection of the target or “normal” sample. Section 4.2 describes the assessment of QC samples.

FD samples will be collected at a minimum frequency of **one FD per sampling event**. An FD is an independent sample collected as close as possible to the original sample from the same source, and is used to assess sampling precision. FDs will be given a unique sample identifier and packaged in the same manner as normal samples so that the laboratory cannot distinguish between normal samples and duplicates. Each FD will be taken using the same sampling and preservation methods as other samples. The location the FD was collected must be documented on the field sheets.

Laboratory QC samples will be collected to perform MS and MSD analyses and will be collected at a frequency of **one MS/MSD per sample event**. A matrix spike is an aliquot of a sample spiked with a known concentration of target analyte(s). An MS analysis provides a measure of the method accuracy. The MSD is a laboratory split sample of the MS and is used to determine the precision of the method. Twice the normal sample volume will be collected for laboratory QC samples. Laboratory QC samples will be labeled as such on sample bottles and chain-of-custody.

Temperature blanks provide a means of verifying that samples have been maintained at the proper temperature (4 °C) following collection and during transport to the laboratory. **One temperature blank will be included with each cooler shipment** containing samples (regardless of targeted analysis) sent to the laboratory. A temperature blank consists of a sample vial filled in the field with de-ionized water, handled like an environmental sample, and returned to the laboratory with the samples for analysis.

3. Field and Laboratory Quality Control

This section summarizes the field and laboratory QC for the surface water and groundwater data collected under the CMP. These procedures are applicable to both surface water and groundwater sampling, unless specified separately.

3.1 Sample Identification

Sample labels will be affixed to containers prior to sample collection. Labels will use the following system for designation:

Groundwater samples: yymm – XX

Surface water samples: yymm – CR-XX or yymm – D-XX

Notes:
XX--identifies the monitoring well or surface water sample station number (e.g., P-25, SA-11, or CR-1).
yymm--identifies the year and month the sample is collected (e.g. 2005 = May 2020).

A fictitious identification number and sample time will be assigned to all groundwater FD samples. For surface water, duplicates will be labeled as QA samples with no time of sampling.

3.2 Sample Documentation

Specific information and observations should be recorded during sampling on dedicated sampling field data sheets or in a bound field notebook. The most important information to document includes the following:

- Sampling team personnel;
- Equipment model and calibration information for each meter used in the field;
- Monitoring well purging data (including purge rate, total volume removed during purging, and water levels at the beginning and end of the purging process);
- Field parameters (temperature, pH, and specific conductance) collected during monitoring, well purging, or surface water measurements;
- Management of purge water (i.e., discharge onto ground);
- Sampling data including sample identification, types of bottles filled, and analyses to be performed on each bottle, as well as method of collection (peristaltic or submersible pump), visual description of the water, and date and time samples were collected;

- Miscellaneous observations regarding well integrity, other nearby field activities, and equipment problems/troubleshooting measures.

Dedicated field sampling forms provide a convenient format for recording all of the above information for groundwater sampling.

3.3 Sample Handling

Specific procedures for sample packaging and shipping will be followed to ensure sample quality and minimize container breakage during transport to the laboratory. Sample handling includes sample preservation, sample custody, sample packaging, and sample shipment procedures as described below.

Sample Preservation

Some sample types require preservation to retard biological action, slow hydrolysis, and reduce sorption effects. Preservation methods generally consist of pH control through chemical addition (e.g., H_2SO_4, HNO_3, etc.), refrigeration (chill to 4 degrees Celsius), and protection from light (e.g., use amber glass bottles).

Samples will be placed in an ice-chilled cooler immediately after collection and held under chain of custody until samples are ready for packaging and shipment. When a chemical preservative is needed for selected parameters, the laboratory will provide bottles with appropriate preservatives (e.g., H_2SO_4, HNO_3, etc.) already added. Bottles prepared with preservation will be pre-labeled and identified as "preserved" to distinguish them from non-preserved bottles.

Sample Custody (Chain-of-Custody Record)

Field personnel will maintain custody records for all samples collected as part of the CMP. A chain-of-custody record will be completed for each shipping container and the information will be consistent with the sample identification labels.

The following information is to be included in the chain-of-custody form:

- Sample number
- Signature of sampler
- Date and time of collection
- Place of collection
- Type of sample
- Sample identification number
- Type of container
- Inclusive dates of possession
- Signature of receiver

In addition to the labels, seals, and chain-of-custody form, other components of sample tracking include the field data sheets, sample shipment receipt, and laboratory logbook.

Sample Packaging

Samples to be shipped to the contract laboratory for analyses will be handled and packaged appropriately to maintain complete chain-of-custody records and prevent damage during shipment. Coolers, provided by the contract laboratory, will be used for shipping sample containers. Bubble wrap will be used to pack and cushion the sample containers in the cooler. The chain-of-custody form will be placed in a plastic bag and attached to inside of the cooler lid. Chain-of-custody seals will be attached at both the front and back of the cooler lid. The name and address of the receiving laboratory will be placed in a position clearly visible on the outside of the cooler, and the lid will be secured with strapping tape.

Sample Shipment

Samples may be hand-delivered to the laboratory, if possible. If shipping is required, samples will be shipped in accordance with Department of Transportation-approved procedures for hazardous substances. Samples will be shipped via overnight courier (e.g., FedEx) to the contracted laboratory for analysis. Shipping would occur as follows:

- Coolers will be shipped to the appropriate laboratory by overnight courier (identified below). All samples will be shipped on the same day of sample collection and conform to applicable hold-times. The field sampler shall verify samples were received by the laboratory, and troubleshoot if needed.
- Surface water samples will be shipped directly to Anatek Laboratories located in Spokane, Washington.
- Groundwater samples will be shipped directly to Anatek Laboratories located in Spokane, Washington.

3.4 Calibration of Field Equipment

The following field equipment will be used to support the groundwater and surface water sampling activities:

- Electronic groundwater level sounder (groundwater only)
- A water quality meter that can measure the following field parameters (YSI-Pro 1030 or equivalent):
  - pH meter with temperature compensation
  - temperature
  - Conductivity with temperature compensation (Specific conductivity)
  - Dissolved oxygen
  - Streamflow discharge velocity meter (Marsh-McBirney Model 2000 flow meter or equivalent)

Calibration will be performed prior to each sampling event per the manufacturer's specifications. Recalibration will be performed, as needed, if inconsistent readings are obtained as determined by the field team leader. Field meter accuracy and range for each parameter is included in Table 2-1 for surface water and Table 5 for groundwater.

3.5 Decontamination of Sampling Equipment

Some of the sampling equipment used for surface and/or groundwater sampling is dedicated to a specific well (e.g., dedicated polyethylene tubing for the peristaltic pump) or sample stations. The sample containers are provided by the contract laboratory for each sampling event and are discarded after use.

All non-dedicated field equipment used during sampling activities will be decontaminated before use and between sampling locations using the following procedure:

- Wash with non-phosphate detergent (Alconox or equivalent)
- Rinse with deionized water
- Air dry

3.6 Management of Purge Water

Consistent with the protocol established in the *L-Bar Material Removal and Compliance Monitoring Work Plan* (CH2M HILL, 2001a), excess purge water from groundwater sampling will be discharged onto the ground near the well. For a given sampling event, the purge volume is typically less than 1 gallon per well for low-flow sampling and typically less than 7 gallons per well for submersible pump sampling from the three SA wells (SA-10, SA-11, SA-14).

3.7 Laboratory Quality Control Procedures

Laboratory QC procedures will include the following:

- Methodology and QC according to the analyte-specific methods listed in Appendix B (Table B-3 for surface water and Table B-4 for groundwater).
- Instrument calibration and standards as defined in the methods listed in Appendix B (Table B-3 for surface water and Table B-4 for groundwater).
- Laboratory blank measurements at a minimum 5 percent or 1-per-batch frequency
- Accuracy and precision measurements at a minimum of 1 in 20, 1 per set
- Laboratory documentation

4. Data Management, Analysis, & Reporting

This section provides a summary of the data management, assessment, and reporting of L-Bar surface water and groundwater data.

4.1 Data Management

The following sub-sections describe data management, including data recording, data reduction, and archives.

Data Recording

Field observations and measurement data will be recorded on dedicated field forms (or field notebook) to create a permanent record of field activities. All hand-entered data will be subjected to a review by a second person to minimize data entry errors. A check for completeness of field records (logbooks, field forms, databases, electronic spreadsheets) will ensure that all requirements for field activities have been fulfilled, complete records exist for each activity, and the procedures specified in this CMP have been implemented. Field documentation will ensure sample integrity and provide sufficient technical information to recreate each field event using the guidelines in Section 3.

Data Reduction

Data collected under the CMP will be reviewed by the respective field sampling leaders to determine if the qualitative parameters of representativeness and comparability have been achieved. In general, the review will be accomplished by comparing the chain-of-custody and field notebook entries with the sampling requirements herein.

Upon receipt of the invalidated electronic data from the laboratory, the data will be reviewed and uploaded to the respective project databases. Groundwater data are uploaded by NWA's contract s data manager into Microsoft Access® database; surface water data are uploaded by SCCD data manager into Microsoft Excel®. The most recent sampling results are compared against historic conditions. If the reported concentrations of a given sample from a specific location are inconsistent with historical data, then efforts will be made to determine if the data reflect an actual change in environmental conditions at that sampling location, or if the integrity of the sample was compromised during collection, preservation, shipping, or analysis. Conversely, if some level of analyte historically present in samples from a specific location is no longer present, then similar efforts will be made to confirm that change in concentration. Corrective actions will be taken to determine if the data meet project goals. If the data do not meet project goals, then the need for additional sampling and analysis will be determined by the respective sampling leaders.

Data Storage and Archives

Data generated as part of the L-Bar CMP will be handled and reviewed in accordance with the procedures outlined above. All collected data for all parameters will undergo three stages of review including:

(1) in the field during and immediately after sample collection with the methods and procedures described in Section 2 (sampling procedures), Section 3 (field and laboratory quality control), and in accordance with SOPs in Appendix C (surface water) and Appendix D (groundwater);

(2) at the laboratory according to the SOPs per analyte-specific methodology;

(3) outside the laboratory via the data assessment criteria described in Section 4.2.

Surface water quality data are archived by SCCD data manager via summary table format (as Microsoft Excel® spreadsheets). All the analytical groundwater data received from the laboratory are transferred directly from the laboratory's electronic data deliverable into a Microsoft Access® database maintained by NWA's contract environmental consultant.

Hard copies of the data reports received from the laboratories are filed chronologically and stored separately from the electronic files. Hard copies of data signed by a representative of the analytical laboratory will be compared to any electronic versions of the data to confirm that the conversion process has not modified the reported results. Complete analytical data packages for individual surface water and groundwater monitoring events are available from the sampling leads upon request (contact information provided in Appendix A).

4.2 Data Assessment

Data reviews will be performed to assess data quality relative to the data quality objectives. Quality control samples will be used to facilitate the quality review and will be collected as described in Section 2.2.2 (*Surface Water Analytical Suite and Field Measurements*) and Section 2.3.2 (*Groundwater Analytical Suite and Field Procedures*). Assessment of data for precision, accuracy, and completeness will be performed by NWA's contract environmental QA Manager in accordance with the quantitative definitions in the following subsections as detailed in *National Functional Guidelines for Inorganic/Organic Data Review* (USEPA, 1994, 1999, 2002b). Data reviews will typically be conducted and included in the 5-year review reports (described in next section). The following information describes the primary quality review parameters.

Representativeness is a measure of how closely the measured results reflect the actual concentration or distribution of the chemical compounds in the samples. Sampling plan design, sampling techniques, and sample handling protocols (e.g., storage, preservation, and transportation) have been developed and are discussed in previous sections of this document. Proposed documentation will establish that protocols have been followed and sample identification and integrity assured. Field duplicate samples will be used to assess method variation. Laboratory sample retrieval, storage, and handling procedures have also been developed and are discussed in subsequent sections of this plan. Laboratory method blanks will be run at the minimum frequency of 5 percent or one-per-batch to assess laboratory contamination.

Comparability of the data will be evaluated by using standard laboratory methods and procedures, which have been defined or referenced in this document. Data comparability will be maintained through the use of consistent methods, consistent units, and well-defined detection limits. Tables B-1 through B-4 (Appendix B) list the specific analysis parameters and applicable methods. Detection limits, as applicable, are also presented in Tables B-1 through B-4 of Appendix B. The target detection limits for the project will be MRLs as provided by the current contract laboratory (Anatek Laboratories in Spokane, Washington). Detection limits are established using pure standards; during measurement of an actual sample, detection limits may be elevated because of interference from other components in the matrix. This cannot be predicted ahead of time but will be reported if it occurs.

Accuracy is an assessment of the closeness of the measured value to the true value. The accuracy of chemical test results is assessed by spiking samples with known standards and establishing the average recovery. In general, for organics, two types of recoveries are measured: matrix spike recoveries and surrogate spike recoveries. For a matrix spike, known amounts of standard compounds identical to the compounds present in the sample of interest are added to the sample. For a surrogate spike, the standards are chemically similar but not identical to the compounds in the fraction being analyzed. The purpose of the surrogate spike is to provide quality control on every sample by constantly monitoring for unusual matrix effects and gross sample processing errors. For inorganics, generally only matrix spikes are measured. A quantitative definition of average recovery is given below. Accuracy measurements will be carried out at a minimum frequency of one per laboratory batch for each matrix (i.e., groundwater and surface water). Target quantitative accuracy objectives are listed in Tables B-3 (surface water) and B-4 (groundwater) of Appendix B.

For measurements where matrix spikes are used, accuracy may be quantified as follows:

$$\%R = 100\% \times \left[\frac{S - U}{C_{sa}}\right]$$

where:

$\%R$ = percent recovery
S = measured concentration in spiked aliquot
U = measured concentration in unspiked aliquot
C_{sa} = actual concentration of spike added

For situations where a standard reference material (SRM) is used instead of or in addition to matrix spikes, use the following:

$$\%R = 100\% \times \left[\frac{C_m}{C_{sm}}\right]$$

where:

$\%R$ = percent recovery
C_m = measured concentration of SRM
C_{sm} = actual concentration of SRM

Precision of the data is a measure of the data spread when more than one measurement is taken on the same sample. For duplicate measurements, precision can be expressed as the relative percent difference (RPD). A quantitative definition of RPD is given below. Precision measurements will be carried out in the laboratory at a minimum frequency of one per laboratory batch for each matrix (i.e., groundwater and surface water). Target quantitative precision objectives are listed in Tables B-3 (surface water) and B-4 (groundwater) of Appendix B.

If calculated from duplicate measurements, precision may be quantified as follows:

$$\text{RPD} = \frac{(C_1 - C_2) \text{ x } 100\%}{(C_1 + C_2)/2}$$

where:

RPD = relative percent difference
C_1 = larger of the two observed values
C_2 = smaller of the two observed values

If calculated from three or more replicates, use relative standard deviation (RSD) rather than RPD, as follows:

$$\text{RSD} = (s / \bar{y}) \text{ x } 100\%$$

where:

RSD = relative standard deviation
s = standard deviation
$\bar{y}$ = mean of replicate analyses

Standard deviation, s, is defined as follows:

$$s = \sqrt{\frac{\sum(y_i - \bar{y})^2}{n-1}}$$

where:

s = standard deviation
y_i = measured value of the i^{th} replicate
$\bar{y}$ = mean of replicate analyses
n = number of replicates

Completeness is a measure of the amount of valid data obtained from the analytical measurement system. The quantitative definition of completeness is given below. The target completeness objective will be 90 percent; the actual completeness may vary depending on the intrinsic nature of the samples. The completeness of the data will be assessed during quality control reviews.

Completeness is quantified as follows:

$$\%C = 100\% \times \left[\frac{V}{T}\right]$$

where:

%C = percent completeness
V = number of measurements judged valid
T = total number of measurements

4.3 Reporting

CMP results will be submitted to Ecology and the project team in two separate types of submittals, including (1) concise year-end annual data summaries, and (2) five-year review data analysis reports. Details regarding these two types of submittals are provided below.

Annual Data Summary Submittals

Data collected under the CMP will be summarized and reported annually to Ecology's Site Manager. Annual data summaries will be prepared separately for surface water and groundwater, respectively, by the sampling leads for each media. Annual data summaries will include tabulated data summaries only for that year. Interpretation and evaluation in the annual reports will be limited to identification of any potentially significant "anomalies" or concerns that may require early attention, before consideration in the more comprehensive 5-year reports (discussed below). Annual data summary submittals will be completed by the end of February of the following year (for example, the 2013 annual submittal will be completed by February 2014).

Five-Year Review Data Analysis Reports

The primary objective of the CMP is to evaluate changes in groundwater and surface water quality in response to the RAs/source removal activities. *Five-year Review Data Analysis Reports* will be developed to:

- Satisfy regulatory site-wide monitoring requirements per MTCA under Agreed Order No. DE 00TCPER-984; and to support Ecology's routine Periodic Review per MTCA Chapter 173-304-420(1);
- Evaluate shallow groundwater and onsite (West Ditch) surface water quality improvements attributable to source removal activities;
- Evaluate the ongoing effectiveness of natural attenuation processes for selected L-Bar indicator constituents in shallow groundwater and surface water;
- Assess progress towards and comparison of groundwater quality to preliminary cleanup levels;

- Evaluate surface water quality conditions in the Colville River reach adjacent to the L-Bar site to compliment the groundwater analyses.

To support these reporting objectives, key elements of 5-year reports include the following analyses to be performed in future reporting efforts:

- A summary of hydrologic conditions for surface water and groundwater during a period in which the water quality results are evaluated. Surface water discharge is plotted on time-series plots for stations D3 (West Ditch), CR1 (Colville River upstream of site), and CR3 (Colville River downstream of site). Groundwater analyses include development of site hydrograph for the period of interest, and recent groundwater flow maps illustrating the April (seasonal high) and October (seasonal low) groundwater flow direction.
- Groundwater quality results include the following analyses:
  - Descriptive statistics including min, max, mean, standard deviation, frequency of detection, and number of observations for all parameters.
  - Time-series concentration plots for all parameters for the period of record.
  - Trend evaluation using primary indicator parameters and generally focusing on the period following source removal actions (i.e., data collected since 2004; refer to Table 1 for a summary of significant activities). Initial trend evaluations in 2007 and 2010 used the Mann-Kendall method and are recommended for future analyses.
  - Comparison of recent concentrations to established groundwater cleanup levels. Refer to Table 5 for preliminary groundwater cleanup levels as developed in the *L-Bar Cleanup Levels Development and Feasibility Study Report* (CH2M HILL, 1999).

- Surface water quality results include the following analyses:
  - Descriptive statistics including min, max, mean, standard deviation, frequency of detection, and number of observations for all parameters.
  - Time-series concentration and loading plots for the primary indicator parameters for the period of record.
  - Surface water/groundwater interaction via estimated load from groundwater to the Colville River reach between stations CR1 and CR3.

Five-year review reports are intended to facilitate and support the routine Periodic Reviews conducted by Ecology (in accordance with MTCA Chapter 173-304-420[1] of the WAC). To date, three *Five-year Review Data Analysis Reports* have been generated, respectively in documents titled *L-Bar Site Compliance Monitoring & Data Evaluation Report, 1996-2006* (CH2M HILL, 2007), *L-Bar Site Compliance Monitoring & Data Evaluation Report, 1996-2010* (CH2M HILL, 2011), and *2017 L-Bar Site Compliance Monitoring Program Data Summary Report and Five-Year Review* (CH2M HILL, 2018). The statistical and graphical methodologies in these reports serve as the baseline evaluation for future reporting efforts.

Potential changes to monitoring and reporting under the CMP will be coordinated with Ecology and documented into an amended CMP (as needed).

5. References

CH2M HILL. 1998. *L-Bar Phase I Remedial Investigation Final Report.*

CH2M HILL. 1999. *L-Bar Cleanup Levels Development and Feasibility Study Report.*

CH2M HILL. 2001a. *L-Bar Material Removal and Compliance Monitoring Work Plan*.

CH2M HILL. 2001b. *Interim Action Source Removal Summary Report – Magnesite Residue Pile, L-Bar Site*.

CH2M HILL. 2004. *Source Removal Summary Report – Covered Pile and Plant Buildings, L-Bar Site.*

CH2M HILL. 2007. *L-Bar Site, Compliance Monitoring and Data Evaluation Report, 1996-2006.* September 2007.

CH2M HILL. 2011. *L-Bar Site Compliance Monitoring and Data Evaluation Report, 1996-2010.*

CH2M HILL. 2007. *L-Bar Site, Compliance Monitoring and Data Evaluation Report, 1996-2006.* September 2007.

CH2M HILL. 2012. *L-Bar Site Compliance Monitoring Program Sampling and Analysis Work Plan Addendum No. 1.* May 2012

Ecology. 2000. *Final Cleanup Action Plan (FCAP).* Washington State Department of Ecology.

Ecology. 2006. *Surface Water Data Review, L-Bar Site (Section 7.0).* Washington State Department of Ecology.

Ecology. 2007. *Standard Operating Procedures for Estimating Streamflow, EAP 024.* Washington State Department of Ecology. February 2007.

Ecology. 2012. Draft *Periodic Review L-Bar Site.*

EPA. 2002a. *Ground-Water Sampling Guidelines for Superfund and RCRA Project Managers*. U.S. Environmental Protection Agency.

EPA. 1994. *National Functional Guidelines for Inorganic/Organic Data Review*. U.S. Environmental Protection Agency.

EPA. 1999. *National Functional Guidelines for Inorganic/Organic Data Review*. U.S. Environmental Protection Agency.

EPA 2002b. *National Functional Guidelines for Inorganic/Organic Data Review.* U.S. Environmental Protection Agency.

United States Geological Survey. 1999. *National Field Manual for the Collection of Water Quality Data*, Book 9, Chapter 4, Technical Water Resource Investigations (USGS, 1999)

Tables

TABLE 1

Timeline of Significant Activities

L-Bar Site - 2020 Compliance Monitoring Program

Period	Activity
circa 1996	Main Ditch Dam and New Lined Stormwater Ditch installed
1996	North Field Land Application Pilot Study
May 1997 - Jul 1997	FB/FBR removal from south perimeter of Mag. Pile
May 1997 - Dec 1999	FB/FBR removal from Mag. Pile
Dec 1997 - Jul 1998	Prilled FB removal from Butler Bldg.
1998	North Field land application
fall/winter 1999	Covered Pile removal pilot test
Jul 2000 - Dec 2003	Covered Pile removal
2001 - Feb 2004	FB/FBR removal from plant buildings
summer 2003	Main Ditch closure
Aug 2003	HDPE Barrier Wall removal
Nov 2003	26 monitoring wells and 16 piezometers decommissioned
2006	L-Bar Site sold to E. Smith Estate
Oct 2006	Surface water monitoring frequency reduced from twice/month to twice/year
Sep 2007	1st Compliance Monitoring and Data Evaluation Report for 1996-2006 submitted
Feb 2011	2nd Compliance Monitoring and Data Evaluation Report for 1996-2010 submitted (Addendum 2)
Feb 2012	1st Periodic Review submitted by Ecology
Aug 2019	Second Periodic Review submitted by Ecology
Feb 2020	3rd Compliance Monitoring and Data Evaluation Report for 1996-2017 submitted (Addendum 3)

TABLE 2-1

Surface Water Monitoring Network, Field Parameters, and Analytical Suite

L-Bar Site - 2020 Compliance Monitoring Program

Stations [(a)]	**Parameter**	**Measurement Type**	**Method**	**Units**	**MRL** [(b)]	**Sampling Frequency**
D3, D2 see note (c)	Discharge	Field Measurement	Bucket and stopwatch; a weir is constructed at D2 to facilitate discharge	Gallons per minute (gpm); converted to cubic feet per second (cfs)	Not applicable; best professional judgement via visual observations estimated to nearest tenth of gallon and second.	Semi-Annually; sampling typically performed in May and October
CR1, CR3 see note (d)	Discharge	Field Measurement	In-stream measurements via Marsh-McBirney Model 2000 [(see note (d)]	Cubic feet per second (cfs)	Up to 19.99 fps; +/- 2%	
D3, D2, CR1, and CR3 see note (e)	Temperature	Field Measurement	YSI Pro1030 or equivalent (f)	Celsius (C)	-5 to 55 °C	
	pH	Field Measurement	YSI Pro1030 or equivalent (f)	unitless	0 to 14	
	Specific Conductance	Field Measurement	YSI Pro1030 or equivalent (f)	mS/cm	0 to 500 mS/cm	
	Ammonia-N	Laboratory Analyzed	EPA 350.1	mg/L	0.05 mg/L	
	Chloride	Laboratory Analyzed	EPA 300.0	mg/L	0.2 mg/L	
CR1, CR3	Dissolved Oxygen	Field Measurement	YSI Pro 1030 or equivalent	% or mg/L	0 to 20 mg/L	

Notes:

(a) Station locations (refer to Figure 1):

CR1: Colville River at Highway 395, River Mile 40.3

CR3: Colville River 300 feet downstream of West Ditch, River Mile 40 (flow measured at CR1)

D2: Mouth of West Ditch

D3: Upper West Ditch

(b) For field parameters, MRL represents the field equipment measurement range.

(c) As described in Section 2.2.2, conditions at station D2 (upper West Ditch) are often stagnant or frozen which precludes a discharge reading.

(d) As described in Section 2.2.2, discharge is estimated at station CR3 during high-flow events based on the sum of discharge measured from CR1 and D2.

(e) As described in Section 2.2.2, water quality samples are collected via **EWI method** where in-stream sampling can be performed safely under fall low flow conditions at Colville River stations CR1 and CR3; whereas **grab samples** are collected during high flow conditions at CR1 and CR3, and during all flow conditions at West Ditch stations D2 and D3.

(f) Note that several field probe models are available to measure the required field parameters and will be based on availability or preference.

TABLE 2-2

Surface Water Monitoring Field Methods by Station and Hydrologic Event

L-Bar Site - 2020 Compliance Monitoring Program

Station		Discharge Methods		Sampling Methods	
		Low-Flow	High-Flow	Low-Flow	High-Flow
West Ditch	D3 (upstream)	B&S	B&S	Grab A	Grab B
	D2 (mouth	B&S	B&S	Grab A	Grab B
Colville River	CR1 (upstream)	In-stream	In-stream©	EWI	EWI
	CR3 (downstream of site)	In-stream	Estimated(d)	EWI	Grab A

Notes:

(a) Discharge Methods:

B&S = manual bucket and stopwatch method (time estimated to nearest second).

In-stream = in-stream field velocity and depth measurements via methods in Appendix C.2 using Marsh-McBirney Model 2000 flow meter.

(b) Sampling Methods:

Grab A = water quality samples collected from the mid-channel width and depth (typical "grab" samples).

Grab B = water quality samples collected via weir outflow at West Ditch mouth station D2.

EWI = equal width increment sampling method as described in Appendix C.1 per USGS methodology.

(c) Discharge under high-flow conditions for station CR1 may be obtained using in-stream measurements via the existing US-395 bridge structure.

(d) Estimated discharge via the sum of CR1 and D2 (given that a bridge structure does not exist at this location).

TABLE 3

Groundwater Monitoring Well Network and Construction Details

L-Bar Site - 2020 Compliance Monitoring Program

Location	Well	TOC Elev. (ft)	Total Depth (ft bgs*)	Screened Interval Depth	Screen Length (ft)	Water-Bearing Formation
Background	P-12	1649.43	14	7 - 12	5	swbu**
	Prod. Well	not surveyed	80	70 - 80	10	confined alluvial sand/gravel
North of Site	P-05	1643.08	12.5	6 - 11	5	swbu
	P-06	1642.33	12.5	4.5 - 9.5	5	swbu
	P-19	1639.97	8	2.5 - 4	1.5	swbu
	P-20B	1642.43	9	4 - 6	2	swbu
	P-25	1639.41	12.5	6 - 11	5	swbu
	P-27	1642.19	12.5	4 - 9	5	swbu
Site Interior	P-09	1643.79	10	4 - 6	2	swbu
	P-13	1646.12	7.5	3.5 - 5.5	2	swbu
Magnesite Residue Pile	SA-10	1672.4	41	35.5 - 40.5	5	swbu, near mag. pile/native silt interface
	SA-11	1668.8	42	36 - 41	5	swbu, near mag. pile/native silt interface
	SA-14	1667.1	37	31 - 36	5	swbu, near mag. pile/native silt interface

Notes:
TOC = Top of Casing
Well construction details approximate
*bgs = below ground surface
**swbu = shallow water-bearing unit

The well casings for SA-10, SA-11, and SA-14 were shortened in circa 1999 following flux bar removal from the Mag. Pile. These were re-surveyed in 2007 and are considered accurate to the nearest tenth of foot.

TABLE 4

Groundwater Analytical Suite and Methods

L-Bar Site - 2020 Compliance Monitoring Program

Wells [(a)]	Analytical Parameter	Method	MRL [(b)]	Cleanup Level [(c)]	Sampling Frequency [(d)]
All Wells: P-05, P06, P-09, P-12, P-13, P-20B, P-25, P-27, SA-10, SA-11, SA-14, and PW (Refer to Fig. 1)	**Primary Indicator Parameters:**				
	Ammonia (NH_4 as N)	EPA 350.1	0.05 mg/L	0.13 mg/L	Semi-Annual (2x/year)
	Chloride (Cl)	EPA 300.0	0.2 mg/L	230 mg/L	Semi-Annual (2x/year)
	Total Dissolved Solids (TDS)	SM 2540C	5 mg/L	1092 mg/L	Semi-Annual (2x/year)
	Secondary Parameters:				
	Nitrate (as N)	EPA 353.2	0.05 mg/L	10 mg/L	Every other year (2x/year)
	Nitrite (as N)	SM 4500B	0.05 mg/L	1 mg/L	Every other year (2x/year)
	Barium (total)	EPA 200.7	0.02 mg/L	1 mg/L	Every other year (2x/year)
	Manganese (total)	EPA 200.7	0.0006 mg/L	0.44 mg/L	Every other year (2x/year)
	Selenium (total)	EPA 200.8	0.001 mg/L	0.0082 mg/L	Every other year (2x/year)
	Thallium (total)	EPA 200.8	0.0002 mg/L	0.00112 mg/L	Every other year (2x/year)
	Turbidity [(e)]	EPA 180.1	0.02 NTUs	N/A	Every other year (2x/year)

Notes:

(a) Well network shown in Figure 1.

(b) MRL = method reporting limit.

(c) Cleanup Levels from Table 4-14 of *L-Bar Cleanup Levels Development and Feasibility Report* (CH2M HILL 1999).

(d) Primary indicator parameters are sampled consistently twice per year (semi-annually); secondary parameters are sampled twice per year every other year. Secondary parameters typically sampled during even years, for example, 2012, 2014, 2016, etc.

(e) Turbidity collected twice per year every other year as a companion with total metals. No cleanup level is available for the site for turbidity.

TABLE 5
Groundwater Field Measurements and Sampling Stabilization Criteria
L-Bar Site – 2020 Compliance Monitoring Program

Analyte	Method	Units	Groundwater Stabilization Criteria (a)
Temperature	Field Reading via YSI Pro 1030 or Equivalent (b)	°C	NA
pH	Field Reading via YSI Pro 1030 or Equivalent	pH Units	±0.1
Specific Conductance	Field Reading via YSI Pro 1030 or Equivalent	mS/cm	± 3%
Depth to Groundwater	Field Sounder	ft	NA

Notes:

a - During purging, three successive readings within stabilization criteria is required prior to sampling; except for purge times greater than one hour.

b - Note that several field probe models are available to measure the required field parameters and will be used on availability or preference.

NA – Not applicable

Figures

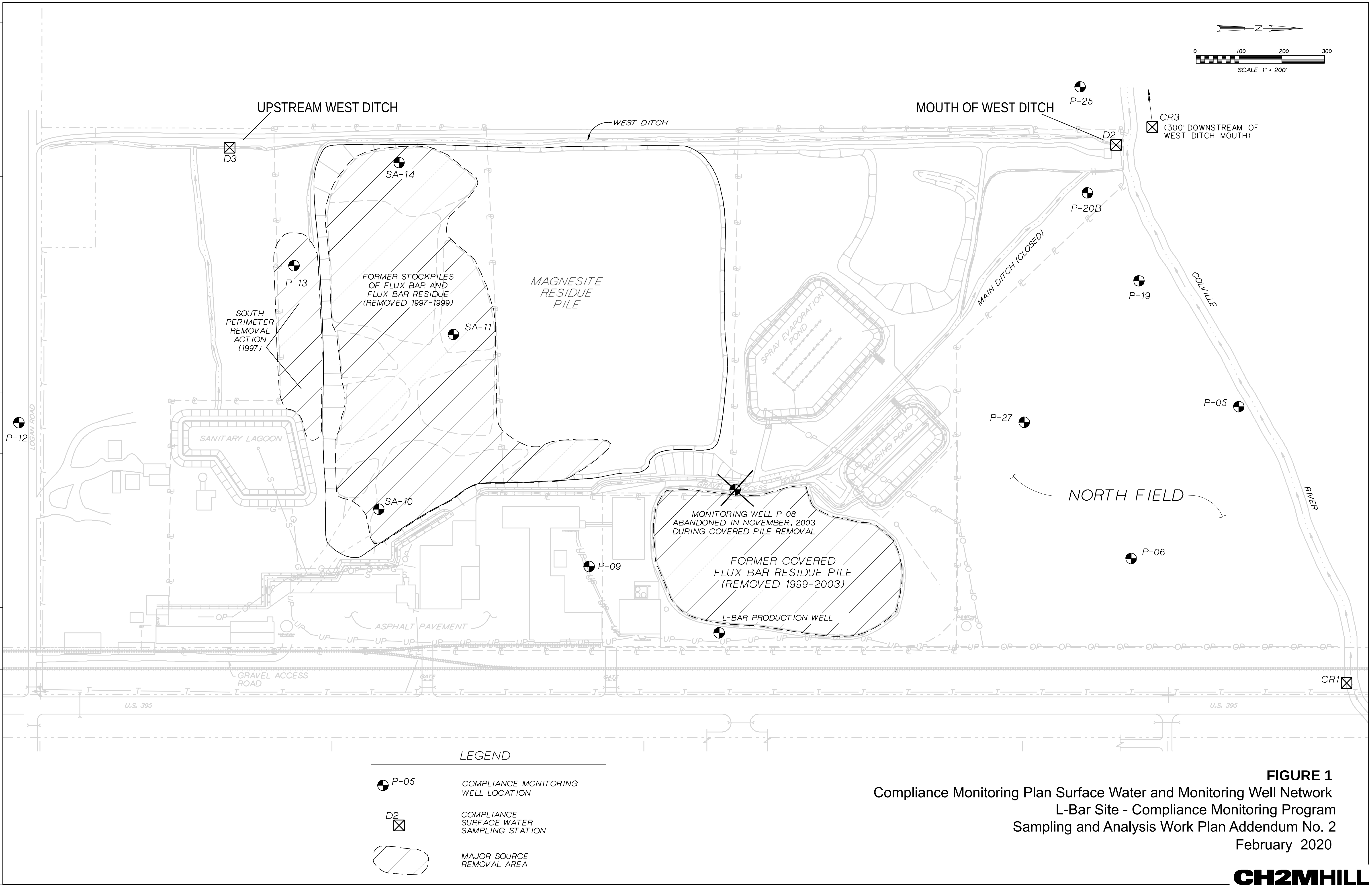

FIGURE 1

Compliance Monitoring Plan Surface Water and Monitoring Well Network
L-Bar Site - Compliance Monitoring Program
Sampling and Analysis Work Plan Addendum No. 2
February 2020

CH2MHILL

\bbh\pro\Alcoalnc\353079\CAD\Drawings\p10d054fAA_Gen.dgn 27-FEB-2007

Appendix A Project Distribution List

Name/Organization	Address/Phone/Email
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Appendix B
Data Uses and Data Quality Objectives

Appendix B.1
Surface Water Data Uses and Data Quality Objectives

Table B-1. Surface Water Data Uses and Data Quality Objectives

Parameter (a)	Anticipated Data Uses	Users	Units	Method	Method reporting Limit (MRL) / Equipment Range, Accuracy (b)
Analytical Parameters:					
Chloride	Comply with ARARs, Risk Assessment, SW Characterization	Regulators, Risk Assessors, Environmental Professionals	mg/L	EPA 300.0	0.2
Ammonia			mg/L	EPA 350.1	0.05
Field Parameters:					
pH	SW Characterization	Environmental Professionals	---	Field Methods	0 to 14 pH units; +/- 0.2 pH units
Specific Conductance			mS/cm		0 to 500 mS/cm; +/- 1% µS/cm
Dissolved Oxygen			mg/L		-0 to 20 mg/L; +/- 0.3 mg/L
Temperature			°C		-5 to 55 °C; +/- 0.2°C
Flow			ft/sec		up to 19.99 ft/sec; +/- 2%

Notes:

(a) = Surface water constituent list was reduced in 2006 upon termination of NPDES program and modelling parameters; Table B-1 (above) presents current CMP suite

(b) = Equipment Range indicates typical effective detection range and accuracy of field equipment for the associated field parameter. Note that the accuracy for specific conductance is shown in µS/cm, while primary units are typically in mS/cm.

Appendix B.2
Groundwater Data Uses and Data Quality Objectives

Table B-2. Groundwater Data Uses and Data Quality Objectives

Parameter (a)	Anticipated Data Uses	Users	Units	Method	Method Reporting Limit (MRL)
Major Anions:					
Chloride	Comply with ARARs, Risk Assessment, GW Characterization	Regulators, Risk Assessors, Hydrogeologists	mg/L	EPA 300.0	0.2
Conventionals:					
Ammonia as N	Comply with ARARs, Risk Assessment, GW Characterization	Regulators, Risk Assessors, Hydrogeologists	mg/L	EPA 350.1	0.05
Nitrate as N			mg/L	EPA 353.2	0.05
Nitrite as N			mg/L	SM 4500B	0.05
TDS	Comply with ARARs	Regulators, Hydrogeologists	mg/L	SM 2540C	5
pH	GW Characterization	Hydrogeologists	NA	EPA 150.1	---
Turbidity	GW Characterization	Hydrogeologists	NTU	EPA 180.8	0.02
Trace Metals:					
Barium	Comply with ARARs, Risk Assessment, GW Characterization	Regulators, Risk Assessors, Hydrogeologists	mg/L	EPA 200.7	0.02
Manganese			mg/L	EPA 200.7	0.0006
Selenium			mg/L	EPA 200.8	0.001
Thallium			mg/L	EPA 200.8	0.0002

Field Parameters:

Parameter	Anticipated Data Uses	Users	Units	Method	Field Equipment Range and Accuracy (b)
pH	GW Characterization	Field Staff / Hydrogeologists	---	Field Methods	0 to 14, +/- 0.2 pH units
Specific Conductance			mS/cm		0 to 500 mS/cm, +/- 1% µS/cm
Temperature			°C		-5 to 55 °C; +/- 0.2°C

Notes:

(a) = Constituents identified as indicator substances in the Cleanup Action Plan (Ecology, 2000)

(b) = Field Equipment Range and Accuracy indicates typical effective detection range and accuracy of field equipment for the associated field parameter. Note that the accuracy for specific conductance is shown in µS/cm, while primary units are typically in mS/cm.

Appendix B.3
Surface Water Analyses Quality Assurance Objectives

Table B-3. Surface Water Quality Assurance Objectives

Parameter (a)	Method	Target Detection Limit	Units	Analytical Accuracy (Percent Recovery)	Analytical Precision (Relative Percent Deviation)	Overall Completeness (Percent)
Analytical Parameters:						
Chloride	EPA 300.0	0.2	mg/L	75-125	± 25	90
Ammonia	EPA 350.1	0.05	mg/L	75-125	± 25	90

Field Parameters:

Parameters	Method	Field Equipment Range (b)	Units	Equipment Accuracy (c)	Calibration (d)
pH	Field Collection	0 to 14	---	+/- 0.2	Prior to field sampling
Specific Conductance		0 to 500	mS/cm	+/- 1% (e)	Prior to field sampling
Temperature		-5 to 55	°C	+/- 0.4	Prior to field sampling
Dissolved Oxygen		0 to 20	mg/L	+/- 0.3	Prior to field sampling
Flow		up to 19.99	foot/sec	+/- 2%	Prior to field sampling

Notes:

(a) = Surface water constituent list was reduced in 2006 upon termination of NPDES program and modeling parameters.

(b) = Field Equipment Range indicates typical effective detection range of field equipment for the associated field parameter.

(c) = Accuracy is based on typical field equipment for the associated field parameter.

(d) = Calibration of field equipment will be performed prior to field sampling and when inconsistent field readings during sampling is suspected by the field team leader.

(e) = The units of the field probe will automatically convert from mS/cm to µS/cm for lower values. The accuracy is provided in µS/cm.

Appendix B.4
Groundwater Analyses Quality Assurance Objectives

Table B-4. Groundwater Analyses Quality Assurance Objectives

Parameter (a)	Method	Target Detection Limit	Units	Analytical Accuracy (Percent Recovery)	Analytical Precision (Relative Percent Deviation)	Overall Completeness (Percent)
Major Anions:						
Chloride	EPA 300.0	0.2	mg/L	75-125	± 25	90
Conventionals:						
Ammonia as N	EPA 350.1	0.05	mg/L	75-125	± 25	90
Nitrate as N	EPA 353.2	0.05	mg/L	75-125	± 25	90
Nitrite as N	SM 4500B	0.05	mg/L	75-125	± 25	90
TDS	SM 2540C	5	mg/L	75-125	± 25	90
pH	EPA 150.1	---	NA	NA	NA	90
Barium	EPA 200.7	0.02	mg/L	75-125	± 25	90
Manganese	EPA 200.7	0.0006	mg/L	75-125	± 25	90
Selenium	EPA 200.8	0.001	mg/L	75-125	± 25	90
Thallium	EPA 200.8	0.0002	mg/L	75-125	± 25	90
Turbidity (b)	EPA 180.8	0.2	NTU	NA	NA	90

Field Parameters:

Parameters	Method	Field Equipment Range (c)	Units	Equipment Accuracy (d)	Calibration (e)
pH	Field Collection	0 to 14	---	+/- 0.2	Prior to field sampling
Specific Conductance		0 to 500	mS/cm	+/- 1% (f)	Prior to field sampling
Temperature		-5 to 55	°C	+/- 0.4	Prior to field sampling

Notes:

(a) = Constituents identified as indicator substances in the Cleanup Action Plan (Ecology, 2000).

(b) = Turbidity added as a companion to metals analysis.

(c) = Field Equipment Range indicates typical effective detection range of field equipment for the associated field parameter.

(d) = Accuracy is based on typical field equipment for the associated field parameter.

(e) = Calibration of field equipment will be performed prior to field sampling and when inconsistent field readings during sampling is suspected by the field team leader.

(f) = The units of the field probe will automatically convert from mS/cm to µS/cm for lower values. The accuracy is provided in µS/cm.

Appendix C
Surface Water Sampling Field Procedures

Appendix C.1

Standard Operating Procedure for Collection of Surface Water Samples

SAMPLE COLLECTION 2.1

By **S.L. Lane, Sara Flanagan, Jacob Gibs,**
D.B. Radtke, W.E. Webb, and F.D. Wilde

Guidelines for selecting sample-collection equipment and related supplies differ, depending on the chemical nature of the target analyte and on whether samples are collected for surface water or ground water. Routine use should be made of checklists, field forms (see NFM 6.0.1 and 6.0.2), and logbooks. Examples of checklists for sample-collection equipment and supplies are provided in section 2.4.

A logbook must be maintained that is dedicated to keeping calibration and maintenance records for each field-measurement, field-analysis, and multiparameter instrument. A field book in which the equipment and methods used for project activities and field-site observations are recorded also is strongly recommended. Logbooks and other records documenting field activities may be requisitioned if the project data are a likely candidate for litigation. Documentation of equipment use and extra quality-control analyses are necessary if study objectives or site conditions result in a departure from published USGS required or recommended procedures.

- Logbooks must be bound so that pages are not readily removable (no loose leaf or spiral notebooks), and pages should be preprinted with consecutive numbers.
- Entries in logbooks or on field forms must be in ball-point pen or permanent non-smudge marker (not pencil or liquid ink) and dated.
- Do not erase incorrect entries or mistakes: draw a single line through the mistake and initial and date it.

All equipment should be maintained and tested on a regular schedule (NFM 6). For example, thermistor thermometers should be checked every 3 to 4 months, along with an annual 5-point calibration (NFM 6.1.2). Equipment checks, calibrations, maintenance, and repair must be entered into the logbook.

2.1.1 SURFACE-WATER EQUIPMENT

Study objectives, flow conditions, and structures (such as a bridge, cableway, or boat) from which sample-collection equipment (a sampler) is deployed must be considered when determining which equipment to use. The equipment selected also depends on whether the stream can be waded or not. To determine whether stream depth and velocity are too great to safely wade the stream (NFM 9), follow this rule of thumb:

👍 **RULE OF THUMB: Do NOT wade in flowing water when the product of depth (in feet) multiplied by velocity (in feet per second) equals 10 or greater.**

Application of this rule varies among individuals according to their weight and stature, and depends on the condition of the streambed.

Two primary types of surface-water samplers are used by the USGS:

- Isokinetic depth-integrating samplers
- Nonisokinetic samplers

2.1.1.A ISOKINETIC DEPTH-INTEGRATING SAMPLERS

An isokinetic depth-integrating sampler is designed to accumulate a representative water sample continuously and isokinetically (that is, stream water approaching and entering the sampler intake does not change in velocity) from a vertical section of a stream while transiting the vertical at a uniform rate (ASTM, 1999; see NFM 4, Appendix A-4-A). Isokinetic depth-integrating samplers are categorized into two groups, based on the method of suspension: hand-held samplers and cable-and-reel samplers.

Types and pertinent characteristics of isokinetic depth-integrating samplers recommended for sampling in flowing water are summarized in table 2-2, illustrated on figure 2-1, and described below. For detailed descriptions of isokinetic depth-integrating samplers, refer to Szalona (1982), Ward and Harr (1990), Horowitz and others (1994), Edwards and Glysson (1999), and Federal Interagency Sedimentation Project at http://fisp.wes.army.mil (accessed March 20, 2003).

For collection of an isokinetic sample, minimum stream velocity must be greater than 1.5 feet per second (ft/s) for a rigid-bottle depth-integrating sampler, or 2.0 ft/s for a US D-96 or US D-99 bag sampler.

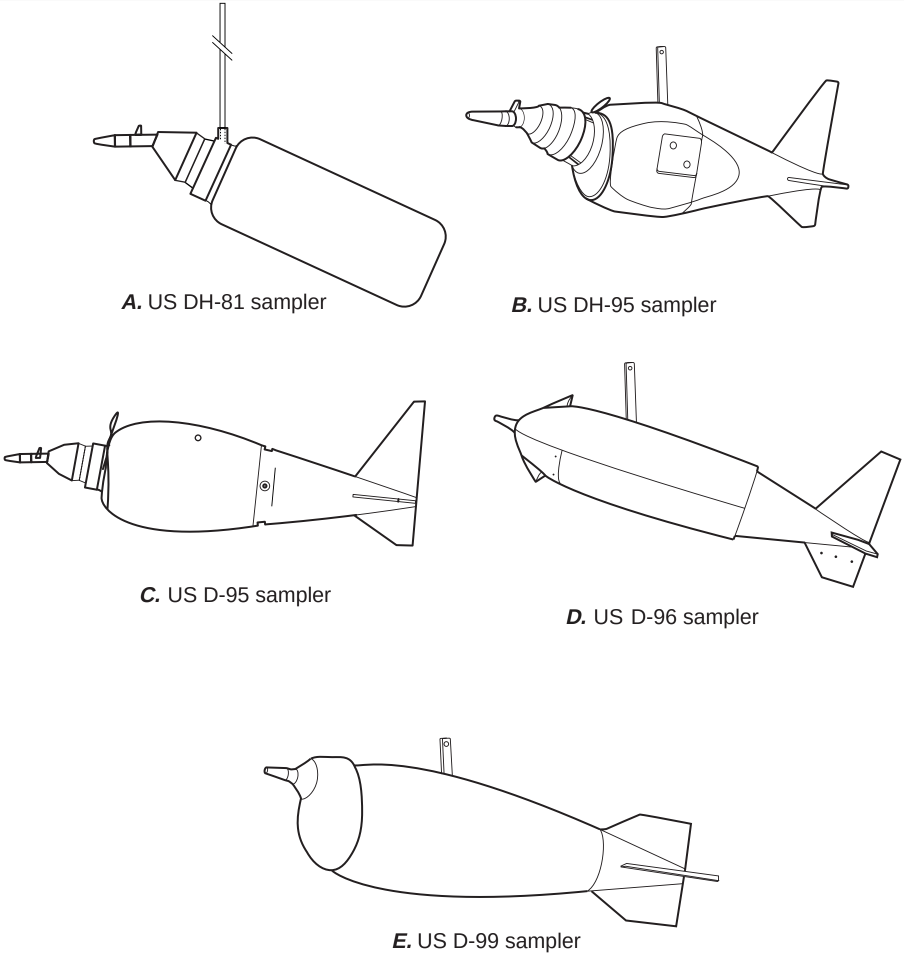
The maximum allowable transit rate (R_t) relative to mean velocity (V_m) for a given sampler varies with nozzle size and sample-bottle size (equipment properties were designed using English units; refer to page CF-1 for conversion to metric units) (table 2-2). **Do not exceed the listed R_t/V_m ratio for the given nozzle and bottle size.** A lower R_t/V_m is better for ensuring that a representative velocity-weighted sample is collected, but care must be taken to not overfill the sampler bottle. **Do not exceed the 15 ft (approximately 4.6 meters (m)) maximum depth of deployment for a rigid-bottle sampler.**

Table 2-2. Isokinetic depth-integrating water-quality samplers and sampler characteristics

[R_t, transit rate in feet per second (ft/s); V_m, mean stream velocity in the vertical being sampled, in ft/s; DH, depth-integrating hand-held sampler; PN, polypropylene cap and plastic (Delrin®) nozzle; PFA, perfluoroalkoxy bottle or bag; C&N, cap and nozzle; PC, plastic coated; PT, polypropylene or PFA bottle; PDC, plastic dip coated; D, depth-integrating sampler; P, plastic nozzle; TFE, tetrafluoroethylene nozzle]

Sampler designation	Sampler construction material	Sampler dimensions			Distance of nozzle from bottom, in inches	Suspension method	Maximum calibrated velocity, in feet per second	Maximum depth, in feet	Sampler container size, in liters	Nozzle intake size,[1] in inches	Maximum transit rate ratio,[2] R_t/V_m
		Length (inch)	Width (inch)	Weight (pound)							
US DH-81	PN or PFA-C&N	[3]6.5	3.2	[3]0.5	[4]4	Hand-held (PC)	7.6	15 15 13.3	1 (PT)	3/16 1/4 [1]5/16	0.2 .3 .4
US DH-95	Bronze (PDC) with PN or PFA-C&N	22	6.6	29	4.8	Hand-held or reel and cable	7.4	15 15 13.3	1 (PT)	3/16 1/4 5/16	.18 .32 .4
US D-95	Bronze (PDC) with PN or PFA-C&N	26	6.7	64	4.8	Reel and cable	6.7	15 15 13.3	1 (PT)	3/16 1/4 [1]5/16	.18 .32 .4
US D-96	Bronze (PDC) with P or TFE nozzle	35	8	132	4	Reel and cable	12.5	110 60 39	3 (PFA)	3/16 1/4 5/16	.4 .4 .4
US D-99	Bronze (PDC) with P or TFE nozzles	47	10	275	9.5	Reel and cable	15	220 120 78	6 (PFA)	3/16 1/4 5/16	.4 .4 .4

[1] Nozzle sizes are those recommended for the application shown.
[2] Refer to NFM 4, Appendix A, for maximum transit-rate ranges, and to Office of Surface Water Technical Memorandum 94.05, dated January 31, 1994.
[3] Length, width, and weight will depend on specific bottle dimensions. Weight indicated is for cap and nozzle only. Handle is plastic coated with clear heat-shrinking tubing.
[4] Distance of nozzle from the bottom will depend on specific bottle dimensions.



A. US DH-81 sampler

B. US DH-95 sampler

C. US D-95 sampler

D. US D-96 sampler

E. US D-99 sampler

Not to scale

Figure 2-1. Isokinetic depth-integrating samplers: (*A*) US DH-81, (*B*) US DH-95, (*C*) US D-95, (*D*) US D-96, and (E) US D-99. (Illustrations courtesy of Federal Interagency Sedimentation Project, Waterways Experiment Station, Vicksburg, Miss.)

The cap-and-nozzle assembly is available in fluoropolymer and polypropylene materials. The same cap and nozzle can be used for the US DH-81, US DH-95, and US D-95 samplers.

- ▶ Use the US DH-81, US DH-95, US D-95, US D-96, or US D-99 samplers (fig. 2-1) to collect samples in flowing waters for all analyses except inorganic gases and volatile organic compounds.
  - — Samples of water for determination of trace elements must contact only noncontaminating materials, typically fluorocarbon polymer or polypropylene.
  - — Samples of water for determination of organic compounds must contact only noncontaminating materials, typically a metal (such as stainless steel), fluoropolymers or fluorocarbon polymers (such as Teflon®[4]), or ceramics (such as hard-fused microcrystalline alumina).
- ▶ Discontinue use of the US DH-48, US DH-59, US DH-76, US D-49, US D-74, US D-77, US D-77 Bag, Frame Bag (FB), US P-61, US P-63, and US P-72 samplers for collecting trace-element samples (refer to Office of Water Quality Technical Memorandum 2002.09 for details): testing indicates that these samplers contaminate samples with measurable concentrations of trace elements.
  - — Some of these samplers may be acceptable for major ions, nutrients, and suspended sediments.
  - — Collect additional quality-control samples if it is necessary to use any of these samplers (Horowitz and others, 1994).

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[4] Teflon is a registered trademark of the DuPont Corporation.

Hand-held samplers

The US DH-81 (fig. 2-1*A*) or US DH-95 (fig. 2-1*B*) sampler is used to collect water samples where flowing water can be waded or where a bridge is accessible and low enough from which to sample. The sampler components (cap, nozzle, and bottle) are interchangeable. Both inorganic and organic samples can be collected with either sampler as long as the construction material of the sampler components (table 2-1) does not affect ambient concentrations of target analytes. Isokinetic depth-integrated samples for bacteria analysis also can be collected with these samplers because the cap, nozzle, and bottle can be autoclaved. All hand-held samplers should be tested and maintained as described on table 2-3. The checklist also applies to cable-and-reel samplers.

Table 2-3. Prefield checklist for hand-held and cable-and-reel samplers

✓	Sampler items	Comment
	Mechanical operation	Test the working condition of the sampler. If tail fin is damaged or broken, sampler will not swim correctly.
	Nozzles	Replace nozzles that have burrs or are damaged. Use only nozzles purchased from the Federal Interagency Sedimentation Project.
	Plastic coating	If plastic coating is damaged or any metal parts are exposed, recoat or touch up with a plastic dip product.
	Sampler is clean	Before field work, clean appropriate parts of the sampler according to procedures described in NFM 3 and store in plastic for transport to the field site.
	Laboratory results from analysis of sampler blank	Make sure the sampler has been quality assured with an annual equipment blank and certified for water-quality use (see NFM 1 and NFM 4).
	Separate sets of sampler components and backup equipment	If at all feasible, for a given field trip when collecting multiple water samples, prepare and use separate sets of sampler bottles, caps, and nozzles for each sampling site. Have backup equipment available on-site.
	Field-cleaning supplies and blank water	If separate sets of sampler components are not available, then clean equipment between sampling sites (see NFM 3) and be prepared to process the number of field blanks needed to document that equipment was adequately cleaned.

When using the US DH-81 (fig. 2-1*A*):

- Use a 3/16-, 1/4-, or 5/16-in. nozzle.
- Make sure that flow velocity exceeds 1.5 ft/s (~0.46 m/s) but does not exceed 7.6 ft/s (~2.32 m/s) (to collect an isokinetic sample).
- Maximum depth of deployment must be within 15 ft (~4.6 m) if using a 3/16- or 1/4-in. nozzle, and within 13.3 ft (~4 m) if using a 5/16-in. nozzle.
- Use caution when sampling in depths that exceed 13.3 ft (~4 m) to avoid overfilling the sampler.

When using the US DH-95 (fig. 2-1*B*):

- Use the 1-L bottle. Use caution when sampling in depths that exceed 13.3 ft (~4 m) to avoid overfilling the sampler.
- To collect an isokinetic sample when using a 3/16-in. nozzle, flow velocity must be between 2.1 to 6.2 ft/s (~0.64 to 1.9 m/s) and depth of deployment should not exceed 15 ft (~4.6 m).
- To collect an isokinetic sample when using a 1/4-in. nozzle, flow velocity must exceed 1.7 ft/s (~0.52 m/s) but be no greater than 7.4 ft/s (~2.25 m/s), and depth of deployment should be within 15 ft (~4.6 m).
- To collect an isokinetic sample when using a 5/16-in. nozzle, flow velocity also should be between 1.7 and 7.4 ft/s (~0.52 and 2.25 m/s), and depth of deployment should not exceed 13.3 ft (~4 m).

Cable-and-reel samplers

Cable-and-reel samplers are used to collect water samples where flowing water should not be waded. These include the US D-95, US D-96, and US D-99 samplers. (Refer to table 2-2 for sampler characteristics and sampling limitations.) Like the hand-held US DH-81 and US DH-95, these cable-and-reel samplers can be used for collecting inorganic and organic samples; however, appropriate sampler components (cap, nozzle, and bottle or bag) must be selected so as not to bias concentrations of target analytes. Isokinetic depth-integrated samples for bacteria analysis also can be collected with these samplers because the cap, nozzle, bottle, and bags can be autoclaved.

The US D-96 Bag sampler uses a perfluoroalkoxy (PFA) or polyethylene bag that is placed in a sliding tray that supports the bag and holds the nozzle holder with nozzle in place. The bag is attached to the nozzle holder with a hook-and-loop strap. The US D-99 Bag sampler uses a 6-L PFA or polyethylene bag that is placed in a chamber behind the nozzle, through an access door.

Metal parts of the US D-95 Bottle sampler and US D-96 Bag and US D-99 Bag samplers must be coated with plastic (for example, Plasti Dip®) and recoated periodically to prevent possible sample contamination from metallic surfaces. **All cable-and-reel samplers should be tested and maintained before use, as described on table 2-3.**

When using the US D-95 Bottle sampler (fig. 2-1*C*):

- Use a 3/16-, 1/4-, or 5/16-in. nozzle. US DH-81 and DH-95 nozzles can be used.
- Make sure that flow velocity exceeds 1.7 ft/s (~0.52 m/s), but no greater than 7.4 ft/s (~2.25 m/s), depending on the nozzle diameter used.
- Use in water less than 13.3 to 15 ft (~4 to 4.6 m) deep (at sea level), depending on the nozzle used and altitude at the site for an isokinetic, depth-integrated sample.

SAMPLE PROCESSING 2.2

***By* S.L. Lane, Sara Flanagan, M.W. Sandstrom,**
K.K. Fitzgerald, F.D. Wilde, and D.B. Radtke

Water samples must be processed as quickly as possible after collection. The equipment most commonly used for sample processing includes sample splitters, disposable capsule filters, filtration assemblies, solid-phase extraction systems, and chambers in which samples are processed and treated with chemical preservatives. Having several sets of cleaned processing equipment on hand is recommended. The equipment and supplies commonly used to process surface-water and ground-water samples are listed in section 2.4.

SAMPLE SPLITTERS 2.2.1

The collection of surface water generally results in a single composite sample. A ground-water sample generally is not collected as a composite; instead, the sample is pumped directly into separate bottles for designated analyses. There are exceptions. For example, ground water withdrawn using a bailer or thief sampler can be collected as a composite sample, provided that sample integrity for the analytes of interest can be maintained.

A composite sample often is subdivided (split) into subsamples for analysis. Each whole-water subsample should contain suspended and dissolved concentrations of target analytes that are virtually equal to those in every other subsample. Use of polypropylene/polyethylene (plastic) churn splitters, the fluorocarbon polymer churn splitter, and the cone splitter are discussed in sections 2.2.1.A and 2.2.1.B, respectively. Testing and comparative data between the splitters are described in Capel and Larson (1996), Horowitz and others (2001), and in Office of Water Quality Technical Memorandum 97.06. Advantages and limitations among the fluoropolymer churn splitter, plastic churn splitter, and cone splitter are shown in table 2-6.

Table 2-6. Advantages and limitations of sample splitters

[L, liter; mg/L, µm, micrometer; milligrams per liter; mL, milliliters; >, greater than; ≤, less than or equal to]

Splitter	Advantages	Limitations
Fluoropolymer churn splitter	Can be used to process samples for both inorganic and non-volatile organic analyses. Simple to operate. Easy to clean. No modification of the splitter design is necessary.	Although it can be used to split samples with particle sizes ≤ 250 µm and suspended-sediment concentrations ≤ 1,000 mg/L, splitting accuracy becomes unacceptable for particle sizes >250 µm and suspended-sediment concentrations >1,000 mg/L. Sample volumes less than 4 L or greater than 13 L cannot be split for whole-water subsamples from this 14-L churn. Samples for bacteria determinations are not to be taken from a churn splitter because the splitter cannot be autoclaved.
Plastic (non-fluorocarbon polymer) churn splitter	Simple to operate. Easy to clean.	Plastic (nonfluorocarbon polymer) churn splitters must not be used to composite samples for determination of organic compounds. Although it can be used to split samples with particle sizes ≤ 250 µm and suspended-sediment concentrations ≤ 1,000 mg/L, splitting accuracy becomes unacceptable for particle sizes >250 µm and suspended-sediment concentrations >1,000 mg/L. When using the 14-L churn, sample volumes that total less than 4 L or greater than 13 L cannot be split for whole-water subsamples. Requires a modified spigot and construction of a funnel assembly. Samples for bacteria determinations are not to be taken from a churn splitter because the splitter cannot be autoclaved.
Fluorocarbon-polymer cone splitter	Used to process samples with suspended-sediment concentrations from 0 to 10,000 mg/L. Samples containing sediment particles ranging in size from very fine clay and silt (1 to 10 µm) to sand-size particles (250 µm) can be split. Samples as small as 250 mL can be split into 10 equal subsamples. Samples greater than 13 L can be processed. Can be used to process samples for both inorganic and nonvolatile organic analyses.	Accuracy of the volume equivalents must be verified before using a new or modified cone splitter. Splitter is awkward to operate and clean in the field. Sample is vulnerable to contamination from atmospheric sources or from improper operation. Splitting accuracy for sediment particles >250 µm or sediment concentrations >10,000 mg/L must be quantified by the user. Samples for bacteria determinations are not to be processed through the cone splitter because the splitter cannot be adequately sterilized. The cone splitter must be level for proper operation.

CHURN SPLITTER 2.2.1.A

The churn splitter is available in either polypropylene and polyethylene plastic (fig. 2-8*A*) or in fluoropolymer plastic (fig. 2-8*B*). Both churn types come in the 14-L size, but the plastic churn also is available in an 8-L size. Splitter advantages and limitations are described in table 2-6. The 8- or 14-L plastic churn splitter is recommended to composite and split surface-water samples for inorganic analyses. The 14-L fluoropolymer churn splitter is recommended to composite and split samples for either inorganic or nonvolatile organic analyses.

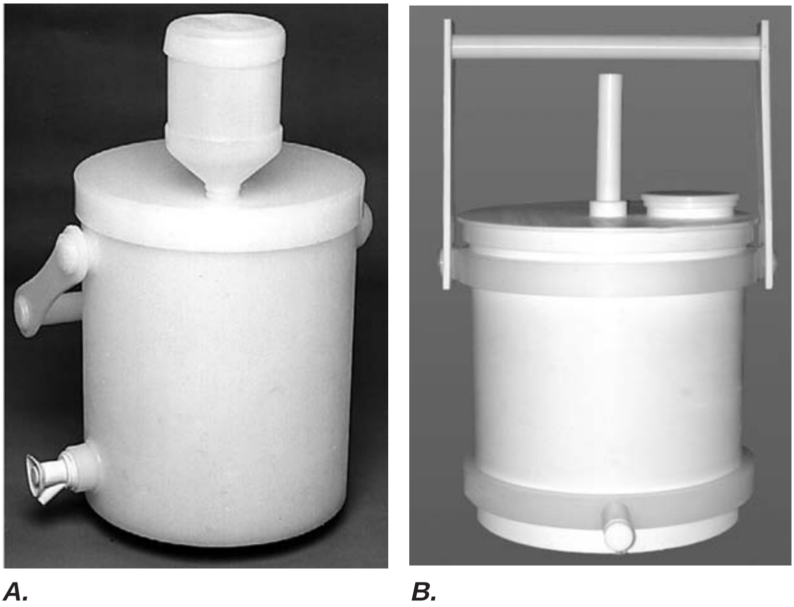

Figure 2-8. Churn sample splitters: (*A*) Plastic churn splitter (from Capel and Larson, 1996) and (*B*) Fluoropolymer churn splitter (from Federal Interagency Sedimentation Project Catalog: accessed December 9, 2002, at http://fisp.wes.army.mil/Catalog%20Page%20US%20SS-1.htm).

- **Trace-element samples:** Do not collect or extract samples for trace-element analyses from a metal container. Use either the plastic or fluoropolymer churn splitter.

- **Organic carbon samples:** Use only the fluoropolymer churn to collect or extract samples for organic-compound analysis. Stainless steel and glass containers also can be used to composite samples for dissolved organic compound analysis. Do not use a plastic churn or container.

- **Churn covering:** To keep the entire churn-splitter assembly clean during sampling and prevent potential contamination, the churn splitter is placed inside two pliable, clear plastic bags (double bagged). These bags should be large enough to completely enclose the churn splitter, including funnel and churn handle, with enough excess material so that the bag openings can be gathered, folded over, and kept closed.

- **Churn carrier:** The carrier is a white plastic container, with lid, large enough to hold the double-bagged churn splitter assembly.
  - The lid of the carrier serves both as a seal for the carrier and as a windbreak when the collected subsample is poured into the churn funnel.
  - The purpose of the carrier is to minimize contamination during transport. In exposed areas, such as bridges and roadways, the carrier can protect against atmospheric sources of contamination, particularly material from motor vehicles.

- **Volume of sample needed:**
  - Subsamples totaling 10 L can be withdrawn from the 14-L churn for whole-water analysis, whereas subsamples totaling 5 L can be withdrawn from the 8-L churn for whole-water analysis.

— Do not use the 4 L remaining in the 14-L churn and the 3 L remaining in the 8-L churn for total, total recoverable, or suspended-material subsamples. However, the sample mixture remaining in either churn can be used for filtered subsamples for the determination of dissolved constituents.

The spigot and lid of the plastic churn splitter must be modified, as described below:

- The original spigot contains a metal spring that introduces a potential source of metal contamination and should be replaced (Horowitz and others, 1994). Purchase the modified spigot from OWQRL, or replace the metal spring with a piece of tubing as follows:

  (1) Cut a 7/8-in. length of 6424-03 Masterflex® tubing. This length is very important to ensure proper operating of the modified spigot. Cut the tubing with a utility knife or something that will cut a straight edge; if edge is jagged, water may leak past the button and possibly contaminate samples.

  (2) Pop button off spigot with a small-blade screwdriver (or push the button in and pull the shaft away from the back).

  (3) Slide the tubing over the sleeve on the inside of the button.

  (4) Slide the tubing that is now attached to the button over the stopper shaft, and compress until the button locks into place.

- Funnel assembly for plastic churn lid: To meet requirements for trace-element sampling, a funnel assembly is inserted into a 1-in.-(2.54 cm-)diameter hole drilled through the lid of the churn splitter (fig. 2-8).

  — The funnel is used when pouring whole-water samples into the churn splitter so that the churn lid can be left on, thus minimizing exposure of the composite sample to atmospheric contamination.

  — To make the funnel assembly, cut the top section (at the shoulder line) from a 1-L polypropylene sample bottle and insert it into the hole drilled in the churn lid. Cut the bottom two-thirds from a 1-L Nalgene® or other larger diameter sampler bottle and use as a funnel cap.

COLLECTION OF WATER SAMPLES

A4.

This chapter of the *National Field Manual* describes standard USGS methods (sampling strategies, techniques, requirements, and recommendations) for routine collection of representative water samples. A representative sample is one that typifies the ambient targeted characteristics of the media of interest at the time of collection. Obtaining representative samples is of primary importance for an accurate description of the environment. In order to collect a representative sample that will yield the information required, (1) study objectives, including data-quality requirements,[2] must be understood in the context of the water system to be sampled and (2) artifacts of the sampling process must be minimized.[3] Field personnel must be alert to conditions that could compromise the quality of a sample.

- ▶ **Think contamination!** To ensure the integrity of the sample, be aware of possible sources of contamination. Contamination introduced during each phase of sample collection (and processing) is additive and usually is substantially greater than contamination introduced elsewhere in the sample-handling and -analysis process. **Collect sufficient quality-control samples.**
- ▶ **Collect a representative sample.** Use appropriate procedures and quality-assurance measures that ensure sample representativeness and integrity and that meet study criteria.

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[2] As used in this report, data-quality requirements refer to that subset of data-quality objectives pertaining to the analytical detection level for concentrations of target analytes and the variability allowable to fulfill the scientific objectives of the study.

[3] The degree to which a sample can be considered representative of a water body depends on many interrelated factors including, for example, temporal and spatial homogeneity of the water body, sample size, and the method and manner of sample collection.

Before field work begins, review the preparations for water sampling described in NFM 1 and the safety requirements described in NFM 9. Sampling plans should be prepared and reviewed in advance. Some programs require chain-of-custody documentation and (or) a prescribed format for sampling and safety plans (SAPs).

- **Never compromise the safety of field personnel.**
- **Become thoroughly familiar with sample processing requirements (NFM 5) before proceeding to collect water samples**.
- **Keep clear and precise field records.** Implement the methods described in this chapter conscientiously and consistently, as appropriate to study objectives and site conditions. **Any departure from standard methods needs to be documented, quality assured, and reported with the data and interpretation of the data.**

Sample collection forms a continuum with sample processing, and information in this chapter (such as collecting quality-control samples) overlaps to some extent with the information in NFM 5 for processing of water samples.

TECHNIQUES TO PREVENT SAMPLE CONTAMINATION

4.0

By **F.D. Wilde and D.B. Radtke**

Contamination of water samples can be prevented by planning the order in which sites will be sampled and by recognizing potential sources of contamination. NFM 1 provides information on reconnaissance of field sites. Sites should be sampled in the order of least to greatest potential for equipment fouling or contamination. The cleanest sites are often those that are in pristine environments, in areas where concentrations of dissolved solids are low, or upstream or upgradient from known or suspected sources of contamination.

The most common causes of sample contamination during sample collection include poor sample-handling techniques, atmospheric input, inadequately cleaned equipment, and use of equipment constructed of materials inappropriate for the analytes targeted for study. Contamination of samples from these sources can be prevented or minimized by adhering to good field practices (table 4-1). Use of Clean Hands/Dirty Hands sampling techniques is described in section 4.0.1, along with other clean-sampling procedures. Field rinsing of equipment to be used to collect and process samples is described in section 4.0.2. The considerations and planning required for collecting ground-water or other samples that contain gases are described in section 4.0.3. Collection of equipment blanks and field blanks is necessary to help identify potential sources of sample contamination (section 4.3). The same equipment that is used to collect (and/or process) environmental samples is to be used to collect (and/or process) blank samples.

Sample at sites with the least contamination or lowest chemical concentrations first.

Table 4-1. Good field practices for collection of water-quality samples

[Modified from "Rules for Trace-Metal Sampling" by Howard Taylor, U.S. Geological Survey, written communication, 1992; NFM, *National Field Manual for the Collection of Water-Quality Data*]

- Be aware of and record potential sources of contamination at each field site.

- Wear appropriate disposable, powderless gloves:
    - Change gloves before each new step during sample collection (and processing).
    - Avoid hand contact with contaminating surfaces (such as equipment, coins, food).

- Use equipment constructed of materials that are relatively inert with respect to the analytes to be collected (NFM 2).

- Use only equipment that has been cleaned according to prescribed procedures (NFM 3).

- Field rinse equipment, but only as directed. Some equipment for some analytes should not be field rinsed.

- Use correct sample-handling procedures:
    - Minimize the number of sample-handling steps.
    - Use Clean Hands/Dirty Hands techniques (table 4-2) as required for parts-per-billion trace-element sampling. Adapt Clean Hands/Dirty Hands techniques for other sample types, as appropriate. Obtain training for and practice field techniques under supervision before collecting water samples.

- Collect (and process) samples in enclosed chambers so as to minimize contamination from atmospheric sources.

- Collect a sufficient number of appropriate types of quality-control samples.

- Follow a prescribed order for collecting samples.

CLEAN-SAMPLING PROCEDURES 4.0.1

Clean-sampling procedures (sometimes called the parts-per-billion or ppb protocol) involve (1) using equipment that is constructed of noncontaminating materials (NFM 2) and that has been cleaned rigorously before field work and between field sites (NFM 3); (2) handling equipment in a manner that minimizes the chance of altering ambient sample composition; (3) handling samples in a manner that prevents contamination; and (4) routinely collecting quality-control (QC) samples. Clean Hands/Dirty Hands (*CH/DH*) techniques separate field duties and dedicate one individual (designated as Clean Hands) to tasks related to direct contact with the sample. *CH/DH* techniques are summarized on table 4-2. Implementation of this protocol requires hands-on training and field-team coordination.[4] **The field team must be trained in and practice these procedures before using them to collect samples.**

Clean-sampling procedures, including *CH/DH* techniques, were developed for collecting (and processing) samples vulnerable to contamination.

- ▶ **Requirement:** Clean-sampling procedures (such as *CH/DH* techniques) are required when collecting samples for analysis of metals and other inorganic trace elements (hereafter referred to collectively as trace elements), as follows:
  - – For trace elements with ambient concentrations at or near 1 µg/L.
  - – For iron, aluminum, or manganese with ambient concentrations to about 200 µg/L.
- ▶ Recommendation: Clean-sampling procedures are recommended when collecting samples for analysis of most trace elements with concentrations to about 100 µg/L.

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[4] A detailed description of Clean Hands/Dirty Hands techniques can be found in Horowitz and others (1994). Clean Hands/Dirty Hands techniques also are included in procedures for equipment cleaning (refer to NFM 3) and sample processing (refer to NFM 5).

▶ Recommendation: Clean-sampling techniques are recommended when collecting samples for analysis of trace-organic compounds and major inorganic elements, particularly when the target analyte could be subject to contamination from field or laboratory procedures at a level that could exceed data-quality requirements.

Table 4-2. Clean Hands/Dirty Hands techniques for water-quality sampling

- Clean Hands/Dirty Hands techniques require two or more people working together.

- At the field site, one person is designated as Clean Hands (*CH*) and a second person as Dirty Hands (*DH*). Although specific tasks are assigned at the start to *CH* or *DH*, some tasks overlap and can be handled by either, as long as the prescribed care is taken to prevent contaminating the sample.

- Both *CH* and *DH* wear appropriate disposable, powderless gloves during the entire sampling operation and change gloves frequently, usually with each change in task. (Wearing multiple layers of gloves allows rapid glove changes.) Gloves must be appropriate to withstand any acid, solvent, or other chemical substance that will be used or contacted.

- *CH* takes care of all operations involving equipment that contacts the sample; for example, *CH*
    - Handles the surface-water sampler bottle.
    - Handles the discharge end of the surface-water or ground-water sample tubing.
    - Transfers sample to churn or cone splitter.
    - Prepares a clean work space (inside vehicle).
    - Sets up processing and preservation chambers.
    - Places equipment inside chambers (for example, sample bottles, filtration and preservation equipment).
    - Works exclusively inside chambers during collection/processing and preservation.
    - Changes chamber covers, as needed.
    - Sets up field-cleaning equipment and cleans equipment.

- *DH* takes care of all operations involving contact with potential sources of contamination; for example, *DH*
    - Works exclusively exterior to processing and preservation chambers.
    - Prepares and operates sampling equipment, including pumps and discrete samplers, peristaltic pump switch, pump controller, manifold system.
    - Operates cranes, tripods, drill rigs, vehicles, or other support equipment.
    - Handles the compressor or other power supply for samplers.
    - Handles tools such as hammers, wrenches, keys, locks, and sample-flow manifolds.
    - Handles single or multiparameter instruments for field measurements.
    - Handles the churn carrier, including outer protective bags.
    - Handles stream-gaging or water-level equipment.
    - Sets up and calibrates field-measurement instruments.
    - Measures and records water levels and field measurements.

FIELD RINSING OF EQUIPMENT 4.0.2

Most equipment used for sample collection and processing is field rinsed with the water to be sampled just before the water samples are collected (some exceptions are described below). The purposes of field rinsing are to condition, or equilibrate, the equipment to the sample environment and to help ensure that all cleaning-solution residues have been removed before sampling begins.[5] The Clean Hands team member is responsible for field rinsing the equipment whenever *CH/DH* techniques are used. Field-rinsing procedures are summarized below for sampling devices and for sample-compositing and sample-splitting equipment. Field-rinsing procedures are discussed in detail in Horowitz and others (1994) and Koterba and others (1995).

Field rinsing of equipment does not substitute for equipment cleaning.

Surface-Water Bottle Samplers and Bag Samplers 4.0.2.A

Sampling devices used to collect water samples from surface water are described in NFM 2. A bottle- or bag-type sampler is used for most routine sampling in streams. If a pump sampler will be used, refer to section 4.1.2, step 4B.

To field rinse a surface-water sampler:

1. Put on appropriate disposable, powderless gloves (gloves).
2. Partially fill and rinse the sampler with the water to be sampled (rinse water). Avoid getting sand in the rinse water.
3. Shake or swirl and then drain the rinse water from the sampler through the nozzle. (For bag samplers, the bag must be removed from the sampler to properly discard final rinse water.)

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[5] Cleaning procedures and subsequent collection of the equipment blank are described in NFM 3.

4.0.2.B Churn Splitter

Surface-water samples commonly are composited in a churn splitter that has a funnel attached to the lid (NFM 2 and NFM 5.1.1.A).

To field rinse the churn splitter:

1. Put on gloves.
2. Pour 2 to 4 L of rinse water from the sampler into the churn splitter (churn) through the top funnel.
3. Remove the churn from the churn carrier, leaving the outer plastic bag inside the carrier. Move the churn disk up and down several times to ensure that the inside of the churn is thoroughly wetted, then swirl the rinse water vigorously in the churn.
4. Pierce a hole through the inner plastic bag to expose the churn spigot and drain the rinse water through the spigot. If sand is present, swirl water vigorously in the churn, open the plastic bag, and partially lift the churn cover to pour the rinse water out of the top of the churn. (Draining the rinse water through the spigot will not adequately remove sand.)
5. After the rinse water has been drained from the churn, rotate the churn in the plastic bag so that the spigot is no longer exposed. Place the inner plastic bag holding the churn into an outer plastic bag and place into the churn carrier.

4.0.2.C Cone Splitter

The cone splitter is required for specific site conditions (NFM 5.1.1.B) and is the sample splitter of choice for some water-quality data-collection programs.

To field rinse the cone splitter:

1. Put on gloves.
2. Uncover the splitter reservoir and pour or pump 2 to 4 L of rinse water into the cone-splitter reservoir.
3. Lightly tap the splitter to dislodge adhering water drops. Discard rinse water.
4. Cover the splitter.

SURFACE-WATER SAMPLING: COLLECTION METHODS AT FLOWING-WATER AND STILL-WATER SITES

4.1

By **W.E. Webb, D.B. Radtke, and R.T. Iwatsubo**

The methods used to collect surface-water samples depend not only on flow characteristics of the surface-water body but also on the following considerations: safety of field personnel (NFM 9); nature of streamflow; field-measurement profiles (NFM 6); temporal and spatial heterogeneity; physical setting; ecological characteristics; weather conditions; fluvial-sediment transport; target analytes; point and nonpoint sources of contamination; and study objectives, including data-quality requirements. Each sampling site needs to be examined and sampled in a manner that minimizes bias caused by the collection process and that best represents the environmental conditions at the time of sampling.

The field team should be thoroughly familiar with procedures and requirements described in the *National Field Manual* and Office of Water Quality Technical Memorandum 99.02[6] before beginning field work. Standard references that provide descriptions of surface-water sampling techniques include: Federal Inter-Agency Sedimentation Project (1986), Ward and Harr (1990), and Edwards and Glysson (1998). Study requirements for quality control (QC) must be checked and previous QC data examined before field work begins.

- ▶ The field team should review requirements and procedures for collection of equipment blanks, field blanks, concurrent samples, and other relevant QC samples before beginning field work (section 4.3).
- ▶ The field team should be adequately staffed and equipped. For example, additional personnel and equipment are required for collection of concurrently collected samples (concurrent replicate samples, section 4.3).

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[6] The technical memorandums referenced in this manual are available on the World Wide Web; see "Selected References and Internal Documents" for memorandum titles, dates, and the Web site address.

4.1.1 FLOWING-WATER SITES

Flowing streamwater is collected using either isokinetic, depth-integrating or nonisokinetic sampling methods. Isokinetic, depth-integrating methods are designed to produce a discharge-weighted (velocity-weighted) sample; that is, each unit of stream discharge is equally represented in the sample (Office of Water Quality Technical Memorandum 99.02). The analyte concentrations determined in a discharge-weighted sample are multiplied by the stream discharge to obtain the discharge of the analyte.

Collection of an isokinetic, depth-integrated, discharge-weighted sample is standard procedure; however, site characteristics, sampling-equipment limitations, or study objectives constrain how a sample is collected and could necessitate use of other methods. If the QC plan calls for collection of concurrent samples, then the relevant procedures must be reviewed and the appropriate equipment prepared (section 4.3).

Nonisokinetic sampling methods, such as those involving use of an automated point sampler, generally do not result in a discharge-weighted sample unless the stream is completely mixed laterally and vertically. Thus, the analytical results cannot be used to directly compute analyte discharges.

Document the sampling method used on the appropriate field form for each sample.

Isokinetic, Depth-Integrated Sampling Methods 4.1.1.A

Collection of isokinetic, depth-integrated samples involves using either an equal-width-increment (EWI) or equal-discharge-increment (EDI) sampling method. The EWI or EDI methods usually result in a composite sample that represents the discharge-weighted concentrations of the stream cross section being sampled. The EWI and EDI methods are used to divide a selected cross section of a stream into increments having a specified width. The term **vertical** refers to that location within the increment at which the sampler is lowered and raised through the water column. EWI verticals are located at the midpoint of each width increment. EDI verticals are located at the centroid, a point within each increment at which stream discharge is equal on either side of the vertical.

Isokinetic samplers usually are used to obtain a discharge-weighted sample along the stream cross section. When using an isokinetic sampler there should be no change in velocity (speed and direction) as the sample enters the intake (fig. 4-1). If properly implemented, EDI and EWI methods should yield identical results. The uses and advantages of each method are summarized below and in table 4-3.

- ▶ Collect isokinetic, depth-integrated samples by using a standard depth- and width-integrating method if analysis of a representative sample from a cross section of flowing water is required for discharge computations. Appendix A4-A and Edwards and Glysson (1998, figures 39-43), provide detailed information about isokinetic, depth-integrating transit rates for collecting samples.

- For isokinetic sampling, the mean velocity of the vertical that is sampled must exceed the minimum-velocity requirement of an isokinetic sampler—the minimum velocity requirement is either 1.5 ft/s for a bottle sampler or 3 ft/s for a bag sampler (Appendix A4-A; NFM 2).
  - The transit rate (the rate at which the sampler is lowered or raised) used to collect an isokinetic, depth-integrated sample is mainly a function of the nozzle diameter of the sampler, volume of the sampler container, stream velocity, and sampling depth (Appendix A4-A; NFM 2). Note that water temperature can affect isokinetic sampling. For example, bag samplers do not work isokinetically in water temperatures that are less than about 7 °C.
  - An error in concentrations of suspended particulates coarser than 62 mm can be significant when the velocity of the sample entering the nozzle and the stream velocity differ significantly. The velocity of the sample entering the nozzle also can be affected by the transit rate: too fast a transit rate will cause a sampler to undersample sand-sized particulates (Edwards and Glysson, 1998).
  - The transit rate must be kept constant during sampler descent through a vertical and also during sampler ascent through a vertical. Although not necessary, usually the same transit rate is used for raising the sampler as was used for lowering the sampler through a given vertical.

RULE OF THUMB: For isokinetic, depth-integrating sampling, do not exceed the designated maximum transit rate.

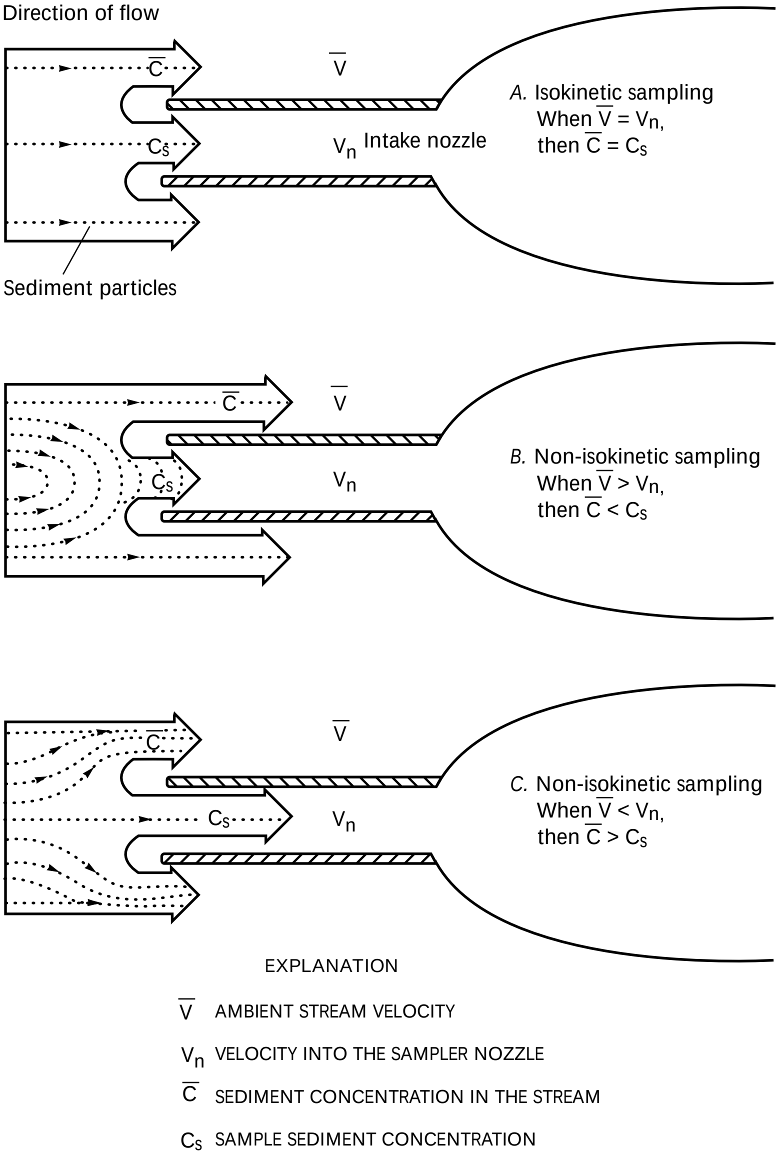


Figure 4-1. Relation between intake velocity and sediment concentration for isokinetic and nonisokinetic collection of water samples that contain particulates greater than 0.062 millimeters (modified from Edwards and Glysson, 1998, p. 13).

The number of increments needed in order to get a discharge-weighted sample at a site is related primarily to data objectives (for example, the accuracy needed) and how well-mixed or heterogeneous the stream is with respect to the physical, chemical, and biological characteristics of the cross section. The recommended number of increments for EWI and EDI methods are discussed in the sections to follow. Edwards and Glysson (1998) describe a statistical approach for selecting the number of increments to be used, based on sampling error and suspended-sediment characteristics.

Selecting the number of increments

- Examine the variation in field-measurement values (such as specific electrical conductance, pH, temperature, and dissolved oxygen) along the cross section (NFM 6).
- Consider the distribution of streamflow (discharge), suspended-materials concentration and particle-size distribution, and concentrations of other targeted analytes along the cross section. Consider whether the distribution or analyte concentrations will change during sample collection.
- Consider the type of sampler that will be used and the volume of sample that will have to be collected for the analysis of the target analytes.
- Avoid side-channel eddies. EDI and EWI methods cannot be used at locations with upstream eddy flow.

Table 4-3. Uses and advantages of equal-width-increment (EWI) and equal-discharge-increment (EDI) sampling methods

EWI method	Advantages of the EWI method
EWI is used when information required to determine locations of sampling verticals for the EDI method is not available, and (or) the stream cross section has relatively uniform depth and velocity. Use EWI whenever: • The location of EDI sampling verticals changes at the same discharge from one sampling time to another. This situation occurs frequently in streams with sand channels.	• EWI method is easily learned and implemented for sampling small streams. • Generally, less time is required onsite if the EWI method can be used and information required to determine locations of sampling verticals for the EDI method is not available.
EDI method	**Advantages of the EDI method**
EDI is used when information required to determine locations of sampling verticals for the EDI method is available. Use EDI whenever: • Small, nonhomogeneous increments need to be sampled separately from the rest of the cross section. The samples from those verticals can be analyzed separately or appropriately composited with the rest of the cross-sectional sample. (Have the sampling scheme approved.) or • Flow velocities are less than the isokinetic transit-rate range requirement. A discharge-weighted sample can be obtained, but the sample will not always be isokinetic. or • The EWI sampling method cannot be used. For example, isokinetic samples cannot be collected because stream velocities and depths vary so much that the isokinetic requirements of the sampler are not met at several sampling verticals. or • Stage is changing rapidly. (EDI requires less sampling time than EWI, provided the locations of the sampling verticals can be determined quickly.)	• Fewer increments are necessary, resulting in a shortened sampling time (provided the locations of sampling verticals can be determined quickly and constituents are adequately mixed in the increment). • Sampling during rapidly changing stages is facilitated by the shorter sampling time. • Subsamples making up a sample set may be analyzed separately or may be proportionally composited with the rest of the cross-sectional sample. • The cross-sectional variation in constituent discharge can be determined if subsample bottles are analyzed individually. • A greater range in velocity and depths can be sampled isokinetically at a cross section. • The total composite volume of the sample is known and can be adjusted before sampling begins.

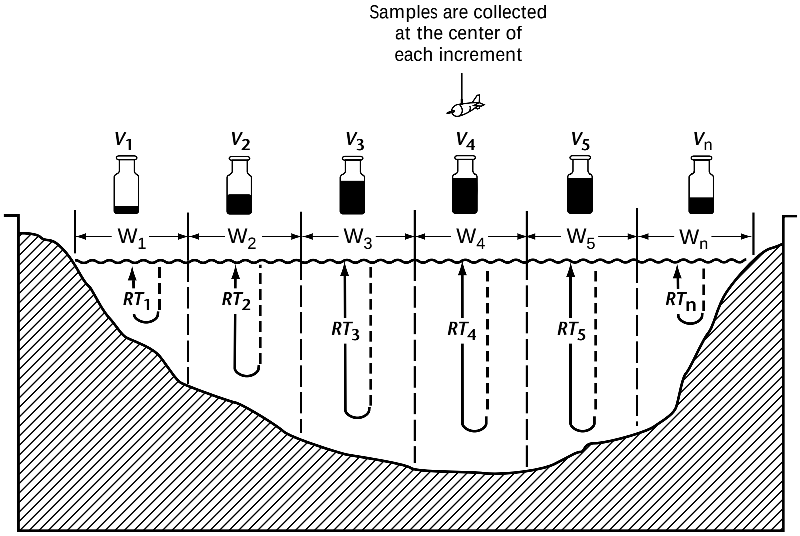
Equal-width-increment (EWI) method

For the EWI sampling method, the stream cross section is divided into a number of equal-width increments (fig. 4-2). Samples are collected by lowering and raising a sampler through the water column at the center of each increment. (This sampling location is referred to as the vertical.) The combination of the same constant transit rate used to sample at each vertical and the isokinetic property of the sampler results in a discharge-weighted sample that is proportional to total streamflow.

- ▶ **Isokinetic sampling is required for the EWI method.** Use isokinetic, depth-integrating sampling equipment (NFM 2).
  - – Use the same size sampler container (bottle or bag) and nozzle at each of the sampling verticals (fig. 4-2).
  - – Collect samples using the same transit rate at each vertical during descent and ascent of the sampler. The transit rate must be constant and within the operational range of the sampler (Appendix A4-A).
- ▶ Composite the subsamples from all verticals in a churn splitter or process subsamples through the cone splitter (NFM 5).

Do not use EWI when stream velocities are less than the minimum velocity required for the isokinetic sampler selected:

- • 1.5 ft/s for the bottle sampler
- • 3 ft/s for the bag sampler

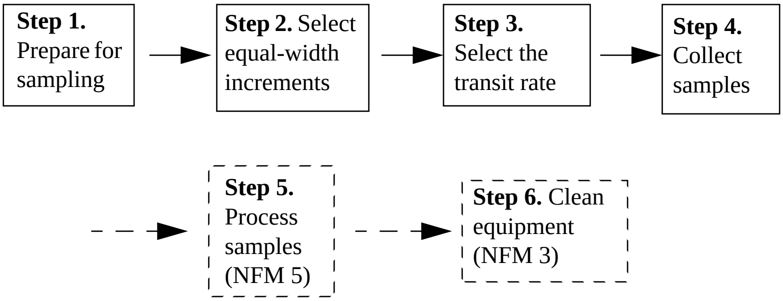


EXPLANATION

RT	TRANSIT RATE (transit rate at each sampling vertical is equal)
W	WIDTH (width of each increment is equal)
V	VOLUME COLLECTED AT EACH VERTICAL IS PROPORTIONAL TO THE DISCHARGE OF EACH INCREMENT
↑	SAMPLING VERTICAL OF EACH EQUAL-WIDTH INCREMENT (SAMPLES COLLECTED)—The vertical transit rate relative to sample volume that is proportional to the stream discharge of each increment

Figure 4-2. Equal-width-increment method for collection of water samples (modified from Edwards and Glysson, 1998).

Guidelines for the EWI sampling method



Be sure that the field effort is adequately staffed and equipped. Check QC requirements before departing—QC samples require additional equipment and supplies.

Step 1. Prepare for sampling[7]

a. Upon arrival at the field site, set out safety equipment such as traffic cones and signs. Park vehicle in a location and direction so as to prevent sample contamination from vehicle emissions.

b. Assemble sampling equipment and set up a clean work space.

  - Organic compounds. Select equipment with fluorocarbon polymer, glass, or metal components if components will directly contact samples to be analyzed for organic compounds. Do not use plastics other than fluorocarbon polymers.
  - Inorganic constituents. Select equipment with components made of fluorocarbon polymer or other relatively inert and uncolored plastics or glass if components will directly contact samples to be analyzed for inorganic constituents. Do not use metal or rubber components for trace-element sampling.
  - Microbiological analyses. Collect samples for microbiological analyses using equipment and techniques described in NFM 7.

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[7] Preparations for water sampling are described in NFM 1, 2, and 3. Consult NFM 5 for sample processing, NFM 6 for field measurements, NFM 7 for biological indicators, NFM 8 for bottom-material sampling and NFM 9 for field safety.

Step 2. Select the number and width of equal-width increments.

a. Visually inspect the stream from bank to bank and longitudinally, observing velocity, width, and depth distribution, and apparent distribution of sediment and aquatic biota along the cross section. Note and document the location of stagnant water, eddies, backwater, reverse flows, areas of faster than normal flow, and piers or other features along the cross section.

b. Determine stream width from a tagline or from distance markings on a bridge railing or cableway.

c. At sites with little sampling history, measure and record the cross-sectional variation of field measurements (such as specific electrical conductance, pH, temperature, and dissolved oxygen). Review the magnitude of the variations along the cross section.

d. Determine the width of the increment. To obtain the number of increments, divide the stream width by the increment width. The number of increments must be a whole number. Increment width is based on study objectives, variation in field measurements and flow, and stream-channel characteristics along the cross section.

   - Collect the subsample at the center of each equal-width increment (the vertical).
   - If the subsample does not represent the mean value for that increment, decrease the increment width until the mean value for the increment is represented. This will increase the number of increments sampled.

e. Locate the first sampling vertical at a distance of one-half of the selected increment width from the edge of the water. Locate all the other verticals at the center of each remaining equal-width increment along the cross section.

   Example:

   - If a stream 56 ft wide has been divided into 14 increments of 4 ft each, the first sampling vertical would be 2 ft from the water's edge and subsequent verticals would be at 6, 10, 14 ft from the water's edge, and so forth.
   - Even if streamflow is divided, as in a braided channel, equal-width increments must be identical from channel to channel, and the same constant transit rate must be used at each vertical.

f. Make slight adjustments to sampling locations, if necessary, to avoid sampling where the flow is affected by a pier or other obstruction.

TECHNICAL NOTE: Sampling near or downstream from large in-stream obstructions such as bridges and piers could result in artificially elevated concentrations of suspended sediments if the sampler is immersed in an eddy that is caused by the obstruction. If it is necessary to include an eddy in the cross section to be sampled, consider treating the eddy as a solid obstruction: subtract the eddy width from that of the total cross section, and determine the width of the increments based on the remaining stream width.

RULE OF THUMB

When selecting the number of equal-width increments:

- Cross-sectional width ≥ 5 ft—use a minimum of 10 equal-width increments.
- Cross-sectional width <5 ft—use as many increments as practical, but equally spaced a minimum of 3 in. apart.

Equipment limitations also constrain the number of increments selected; for example:

- When using a D-95 at maximum depth with a 14-L churn splitter, EWI samples can be collected at approximately 14 verticals. If an 8-L churn splitter is used, samples can be collected at approximately 10 verticals.
- When using a D-77 and a 14-L churn splitter, the maximum average depth must not exceed 5 ft when samples are collected at 10 verticals.

Step 3. Select the transit rate.

a. Refer to Appendix A4-A for guidelines for determining the transit rates for collecting isokinetic, depth-integrated samples. Unless the mean velocity is actually determined, use the trial-and-error method to determine the minimum transit rate.

b. Locate the equal-width increment containing the largest discharge (largest product of depth times velocity) by sounding for depth and either measuring or estimating velocity. At the vertical for this increment, use of the minimum transit rate results in the maximum allowable filling of the sampler bottle or bag during one vertical traverse.

c. Determine the minimum transit rate at this vertical for the type of sampler (bottle or bag), size of sampler nozzle, and the desired sample volume.

  - Approximate the mean velocity of the vertical in feet per second by timing a floating marker (such as a peanut) as it travels a known distance. (A known length of flagging tape tied to the cable where the sampler is attached often is used to measure the distance.) Divide the distance (in feet) by the time (in seconds) and multiply by 0.86.
  - Make sure that the transit rate does not exceed the maximum allowable transit rate to be used at any of the remaining verticals along the cross section. This can be determined by sampling the slowest increment. If the minimum volume of sample (relative to depth of the vertical) is not collected at this vertical, then the EWI method cannot be used at this cross section to collect a discharge-weighted sample (Appendix A4-A).

Guidelines for selecting the transit rate for EWI sampling

- The descending and ascending transit rate must be constant in each direction and must be the same for each vertical along the cross section.
- Do not exceed the maximum allowable transit rate if using EWI. If the transit rate must exceed the maximum allowable rate, use EDI instead of EWI.
- The transit rate selected must be sufficiently rapid to keep from overfilling the sampler. The sampler is overfilled when the water surface in the sampler container is above the bottom edge of the nozzle when the sampler is held in the sampling position.
- The same size sampler nozzle and container must be used at all verticals along the cross section.
- If the total volume collected will exceed the recommended volume for the churn splitter, then a cone splitter must be used.

Step 4. Collect samples.

The sample-collection procedure is the same whether you are wading or using the reel-and-cable suspension method. **Use *CH/DH* techniques, as required (section 4.0.1). Always follow safety procedures (NFM 9)**.

a. Move to the first vertical (midpoint of first EWI near edge of water) and field rinse equipment (section 4.0.2).

b. Record start time and gage height.

c. Lower field-rinsed sampler at the predetermined constant transit rate until slight contact is made with the streambed. Do not pause upon contacting the streambed. Raise the sampler immediately at the same constant transit rate until sampler completes the vertical traverse.

   - Take care not to disturb the streambed by bumping the sampler on it; bed material may enter the nozzle, resulting in erroneous data.
   - Do not overfill the sampler container. Overfilling results in a sample that is not isokinetic and that could be enriched with heavy particulates because of secondary circulation of water through the sampler (from nozzle through air exhaust). This enrichment will result in an artificially increased sediment concentration and will bias particle-size distribution toward heavier and larger particulates.
   - Do not underfill the sampler container (Appendix A4-A). Underfilling will result in a sample that is not isokinetically collected because the maximum transit rate has been exceeded.
   - If the required volume cannot be collected, use the EDI method to obtain discharge-weighted samples.

d. Inspect each subsample as it is collected, looking for overfilling or underfilling of the sampler container and (or) the presence of anomalously large amounts of particulates that might have been captured because of excessive streambed disturbance during sample collection. If you note any of these conditions, discard the sample, making sure there are no residual particulates left in the container, and resample.

e. Move sampling equipment to the next vertical. Maintain the selected transit rate. The volume of the subsample can vary considerably among verticals. Subsamples can be collected at several verticals before emptying the sampler container, as long as the maximum volume of sample in a bottle or bag sampler has not been exceeded. If the container is overfilled, it is necessary to resample.

> TECHNICAL NOTE: The tables in Appendix A4-A apply to the first complete round-trip transit starting with an empty sampler container. These tables cannot be used if the sampler is not emptied between verticals.

f. Continue to the next vertical until no more samples can be collected without overfilling the sampler container. Empty the subsample into a field-rinsed churn or cone splitter and repeat sample collection in the same manner until subsamples have been collected at all the verticals.

- If the total volume of the subsamples to be collected will exceed the operational capacity of the churn, select from the following options: use either a sampler with a smaller bottle or a bag sampler with a smaller nozzle; or use a cone splitter; or use the EDI method, if appropriate.
- To ensure that all particulates are transferred with the sample, swirl the subsample gently to keep particulates suspended and pour the subsample quickly into the churn or cone splitter.
- Sample EWI verticals as many times as necessary to ensure that an adequate sample volume is collected as required for analysis, but sample at each vertical an equal number of times. (The composite cross-sectional sample will remain proportional to flow at the time of sampling.)
- If flow is stable during sampling, then multiple samples can be collected at each vertical during a single traverse along the cross section. If flow is changing, however, study objectives should determine whether to collect multiple samples at each vertical during a single traverse or to collect one sample at each vertical during multiple traverses along the cross section. Document on field forms the method used.

g. Record the following information after all samples have been collected:

  - Sampling end time.
  - Ending gage height.
  - All field observations and any deviations from standard sampling procedures.

Step 5. Process Samples ➜ Refer to NFM 5.

Step 6. Clean Equipment ➜ Refer to NFM 3.

- If the sampler will not be reused during a field trip, rinse sampler components with deionized water before they dry and place them into a plastic bag for transporting to the office laboratory to be cleaned.
- If the sampler will be reused during the field trip, rinse the components with DIW while still wet from sampling and then field-clean while at the sampling site using the prescribed procedures (NFM 3). Reassemble the sampler.
- Collect a field blank, if required, after sampling equipment has been cleaned at the sampling site.
- Place the cleaned sampler into a plastic bag and seal for transport to the next site.

Appendix C.2
Standard Operating Procedure for Measuring Discharge

Washington State Department of Ecology

Environmental Assessment Program

Water Quality Studies Unit

Standard Operating Procedure for Estimating Streamflow

Version 1.0

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Date -

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Date -

QA Approval - William R. Kammin, Ecology Quality Assurance Officer
Date -

EAP024

PROVISIONALLY APPROVED: February 20, 2007

Signatures on File

SOP Revision History

Revision Date	Rev number	Summary of changes	Sections	Reviser(s)

Environmental Assessment Program

Standard Operating Procedure for Estimating Streamflow

1.0 Purpose and Scope

1.1 This document is the Environmental Assessment Program (EAP), Water Quality Studies Unit Standard Operating Procedure (SOP) for Estimating Streamflow.

2.0 Applicability

2.1 This document should be used for all streamflow measurements.

3.0 Definitions

3.1 Fixed Point Averaging (FPA) - An average of velocities over a fixed period of time.

3.2 Reference Point (RP) - A fixed point or datum on the bridge or other structure from which a measurement can be made to the surface of the water under all flow conditions.

3.3 Staff Gage - A graduated measuring device securely fixed to a permanent structure in the streambed from which river stage height can be read directly to the 100th of a foot.

4.0 Personnel Qualifications/Responsibilities

4.1 Trained in safety procedures for work in streams.

5.0 Equipment, Reagents, and Supplies

5.1 Flow/current meter

5.2 Wading Rod

5.3 Field notebook

5.4 Measuring Tape (100 ft or long enough to span the width of the stream)

5.5 2 Stakes

5.6 Life Vest

5.7 Chest Waders

5.8 Staff gage (if used) and equipment for installation

6.0 Summary of Procedure

6.1 Measuring Depth and Velocity of a Stream Cross Section

6.1.1 Selecting a Representative Cross Section to Measure Discharge

6.1.1.1 The selection of a suitable stream cross section for measuring discharge is very important and cannot be over emphasized. Site selection is, in most cases, the most important factor in developing accurate flow information. The limitations of a poor cross section can not be overcome by the ability of the individual taking the measurement. Use the following criteria for deciding which cross section to use:

6.1.1.1.1 The stream reach should be relatively straight and uniform for a long enough distance to provide uniform flow through the measuring section (preferably 200-300 feet upstream and downstream of the measurement site). The site should be free from excessive turbulence.
6.1.1.1.2 The stream channel should be free from vegetative growth and be relatively stable (free from major seasonal scouring or deposition of bed material).
6.1.1.1.3 The stream bed should be relatively uniform with only minor irregularities (no large cobble or boulders).
6.1.1.1.4 During low flow conditions (typically August-October), the stream channel should be confined to a single course.
6.1.1.1.5 The stream bank should be stable and able to contain the maximum stream discharge (floods).

6.1.1.2 If these criteria are met, the cross section should be relatively stable under most conditions and the streamflow should be uniformly distributed across the cross section. It is, however, unrealistic to assume all stream cross sections will meet all of these criteria. Therefore, complete and accurate field notes describing the cross section and noting the exceptions to these criteria are vital when determining the relative accuracy of the discharge measurement.

6.1.2 Site preparation

6.1.2. 1 Ideally, the cross section to be measured will meet all of the selection criteria, however, some will not. If the cross section selected is compromised by excessive aquatic plants, the presence of woody debris, or has minor irregularities in the stream bed (rocks and manageable boulders), an attempt should be made to minimize their impact on flow measurements. This may require physical removal of interference and minor alterations of the streambed. After the cross section has been cleared, inspect the stream banks to ensure they are confining enough to provide a distinct edge. If the streambed has a gentle sloping bank, use rocks or other available material to make a defined steam edge. Care should be taken to ensure that minimal water bypasses these structures. Do not change the section after starting a measurement. Modifying the cross section after velocity measurements have begun may alter the flow characteristics and therefore the accuracy of your measurement.

6.1.3 Dividing the stream channel into segments

6.1.3.1 Approximate stream discharge by multiplying the average velocity by the cross sectional area of the stream. Because most stream velocity and bottom contours vary as you proceed across the stream channel, the cross section is divided into manageable segments.

6.1.3.2 Stretch a measuring tape (tagline) across the stream perpendicular to the cross section to be measured.

6.1.3.3 Anchor the tape to the surrounding vegetation/debris or to stakes driven in for attachment points.

6.1.3.4 Note width of the stream channel and divide into conveniently measurable segments. The total number of segments should be large enough to ensure no more than 10% of the total flow is contained in any one segment (preferably 5%). For example, if the stream is relatively uniform with a width of 12 feet, the distance between segment of one or 0.5 foot would be adequate. If, however, the flow is unequally distributed, measuring points should be closer together where velocity or bottom irregularities are the greatest. In this case the distance would be one foot for uniform segments and 0.5 foot near the area of greatest variability.

6.1.4 Measuring stream velocity of the stream segments

6.1.4.1 Stream velocities not only vary horizontally as one proceeds across the stream cross section, but vertically as well. Currently two methods are used to address vertical variability within a segment, one applies with stream depths less than 2.0 feet and the other for streams over 2.0 feet. For stream segments under 2.0 feet in depth, the velocity is measured at sixth-tenths of the depth (six-tenths method). For streams with depths greater than 2.0 feet, the velocity is measured at two-tenth and eight-tenths of the depth and the results are averaged (two-tenths/eight-tenths method).

6.1.5 Measuring Water Depths and Velocities

6.1.5.1 Measuring Water Depths and Velocities by Wading

6.1.5.1.1 Record site information in the field notes.
6.1.5.1.2 Measure and record stage gage readings or tape down (if available).
6.1.5.1.3 Select a suitable stream cross section for measurement.
6.1.5.1.4 Determine which safety requirements are warranted based on in-stream conditions. Do not proceed if the conditions are not deemed safe by the field crew.
6.1.5.1.5 Prepare cross section by removing debris, rocks and confining stream edges.
6.1.5.1.6 Stretch measuring tape across the stream channel perpendicular to streamflow and note total stream width.
6.1.5.1.7 Divide stream width into segments (15-25) with no more than 10 percent (preferably 5%) in any one.

6.1.5.1.8 Turn current meter on and make sure settings are correct (See Appendix A for current meter instructions).

6.1.5.1.9 Measure the depth of the first segment by reading the water level on the wading rod.

6.1.5.1.10 Adjust the wading rod to the proper depth.

6.1.5.1.11 For < 2.0 feet total depth, use the scale on the wading rod to place the meter sensor at 6 tenths depth.

6.1.5.1.12 For > 2.0 feet total depth (if vertical stratification is abnormal), adjust the wading rod so that the meter sensor is at half the total depth for the 8 tenths depth and double the total depth for 2 tenths depth.

6.1.5.1.13 Record the velocity in the proper column in field notes.

6.1.5.1.14 Proceed across the stream, repeating steps 9-13 at each segment.

6.1.5.1.15 Measure and record the stage height (if available).

6.1.5.2 Measuring Water Depths and Velocities from a Bridge

6.1.5.2.1 Refer to the Stream Hydrology Unit's SOP for Measuring Discharge from a Bridge.

6.1.5.3 Measuring Water Depths and Velocities from a Boat.

6.1.5.3.1 Refer to the Stream Hydrology Unit's SOP for Measuring Discharge from a Boat.

6.1.6 Calculating Stream Discharge

6.1.6.1 Calculate discharge as a summation of discharge in partial areas. Compute discharge in a partial area using the equation:

$$q_x = v_x d_x (b_{x+1} - b_{x-1})/2$$

where: $b(_{x+1})$ = distance from the initial point to the preceding point (feet)
$b(_{x-1})$ = distance from the initial point to the following point (feet)
d_x = mean depth of partial area x
v_x = average velocity in partial area x
q_x = discharge in partial area x (cfs)

6.2 Float Method to Estimate Velocity

6.2.1 When usual flow measurement methods cannot be used (e.g., during extremely high flows, or when equipment is not available), a floating object can be used to estimate velocity. The object can be an orange, a plastic sample bottle partially filled with water, or other semi-buoyant object.

6.2.2 Locate a straight stretch of stream.

6.2.3 Select two cross-sections within the stretch, measure (or estimate) their cross-section area and distance between them. Sites should be far enough apart that float movement between sites exceeds 20 seconds.

6.2.4 Release the float at the upstream site and record the time it takes to reach the downstream site. Repeat twice and average the three measurements. To increase accuracy, release the float at different places across the width of the stream.

6.2.5 Calculate the velocity as distance traveled divided by average travel time.

6.2.6 Calculate the adjusted (true mid-depth) mean velocity of the water by multiplying the surface velocity by 0.85.

6.2.7 Calculate discharge by multiplying velocity by the average cross-sectional area.

6.3 Measuring Flow from Pipes

6.3.1 Volumetric Measurements

6.3.1.1 In this method, discharge is calculated by observing the time required to fill a container of a known volume. A limiting factor of this technique is that it can only be used with small discharges (i.e., where all of the flow can be caught in one container). This technique can also be used to estimate discharge over a weir or at any place where flow is concentrated into a narrow stream.

6.3.1.2 Place bucket or other container below the discharge.

6.3.1.3 Time how long it takes to fill the container. Repeat three times (or more if there are large differences between results).

6.3.1.4 Calculate discharge as the volume of the container divided by the average time to fill it.

6.3.2 Discharge of a Jet of Water

6.3.2.1 This technique can be used on any discharge regardless of size. The limitations are that the pipe must be horizontal and it must be running completely full.

6.3.2.2 Measure or estimate the diameter of the pipe.

6.3.2.3 Measure the distance from the end of the pipe to the spot where the stream of water hits the ground (“x”).

6.3.2.4 Measure the vertical distance from (“x”) to the midpoint of the pipe orifice (“y”).

6.3.2.5 Calculate the velocity as: $V = 4.01(x)/\sqrt{y}$

6.3.2.6 Calculate the area (“A”) of the pipe as: $A = \Pi r2$

6.3.2.7 Calculate the volume by multiplying the area by velocity. Units of measurement must be the same.

6.4 Use of Staff Gage for Estimating Flow

6.4.1 A staff gaging station may be set up at a sample site (preferably at the mouth of the watershed). The purpose of a staff gaging station is to develop a relationship between stream height (stage) and flow. Once this relationship is established, stream discharge may be estimated based on gage heights. Where the flows fluctuate greatly, it may be necessary to set staff gages in series to accommodate a variety of stream levels.

6.4.2 Site Selection

6.4.2.1 The stream course should be relatively straight and free flowing for 200-300 feet upstream and downstream of the measurement site. The site, however, should be free from excessive turbulence.

6.4.2.2 The stream channel should be free from vegetative growth and be relatively stable (free from major seasonal scouring or deposition of bed material).

6.4.2.3 The steam bed should be relatively uniform with only minor irregularities (no large cobble or boulders).

6.4.2.4 During low flow conditions, the stream channel should be confined to a single course.

6.4.2.5 The stream bank should be stable and able to contain the maximum stream discharge (floods).

6.4.2.6 Gaging stations should be located a sufficient distance upstream of tributaries and tidal action to prevent the distortion of stage/discharge measurements.

6.4.2.7 All discharge stages should be measurable somewhere within the reach (it is not necessary to measure low and high flows in exactly the same place.

6.4.3 Staff Gage Installation

6.4.3.1 Attach staff gage vertically on a permanent structure (concrete piling, revetment, etc.) or install in the stream by driving an appropriate post into the substrate and then attaching staff gage to the post.

6.4.3.2 Set the zero point of the staff gage below the lowest level of possible streamflow to prevent negative values of the gage height.

6.4.3.3 Establish a datum point on the gage, and make two or three reference marks at the same level on nearby permanent features. (Use a point on the gage that is above the highest expected gage height to prevent flow-related erosion of the marks.) The datum may also be referenced to an official surveyor's benchmark. Establishing reference elevations allows data to be recovered if the staff gage is destroyed.

6.4.4 Reference Point Measurement

6.4.4.1 The distance from a reference point (RP) to the water surface is measured with a weighted fiberglass measuring tape. The weighted tape is lowered to the water surface just to the point were the wake from the water passing by the weight forms a slight distinctive "V" shape. The distance from the RP to the water surface is recorded to the nearest 100th of a foot.

6.4.4.2 Establish a RP on the bridge by locating or creating a permanent mark near the center of the stream.

6.4.4.3 Find the RP mark on the bridge.

6.4.4.4 Lower the weighted tape until it just touches the water (a distinctive "V" should appear downstream of the weight). Raise the weight to make sure you are just touching the water.

6.4.4.5 Read the tape at the edge of the RP to the hundredth of a foot.

6.4.4.6 Record the time, RP measurement, and the correction factor for the tape (written on the side of the tape) in the field notes.

6.4.5 Establish a Rating Curve

6.4.5.1 Take streamflow measurements over a wide range of gage heights and/or RP measurements. It is very important that measurements are not just made in average flow conditions, but also at high and low flows to develop a rating cure for a wide range of flow conditions. Make sure to note the gage height/RP measurement before and after the flow measurement.

6.4.5.2 Develop a rating curve using regression analysis of instantaneous flow measurement and stage height. Rating curves should be based on sufficient number of measurements to allow a smooth curve to be drawn through the points (usually 8 to 10 measurements).

6.4.5.3 Periodically check the discharge curve, especially after high flows, to ensure the stream bed has been unaltered by sediment deposition or erosion, and that a reasonably accurate rating curve still exists.

7.0 Records Management

(Not Applicable)

8.0 Quality Control and Quality Assurance Section

8.1 QA/QC procedures will be addressed thoroughly on a project-by-project basis in the Quality Assurance Project Plan (QAPP) for the project.

9.0 Safety

9.1 Wading streams is one of the most dangerous activities undertaken by field staff especially during higher flows. Two people are required at all times when streams are to be waded. Life jackets are to be worn if there is any chance of being pushed downstream or being submerged after falling into the water. Life jackets should also be worn when new sites are being established and when-stream conditions to be encountered are unknown.

9.2 If there is any chance of the streamflow being strong enough to potentially cause injury (by being swept downstream into rocks or other dangerous settings, drowning, hypothermia, etc.), do not consider taking a flow cross section. If a safety harness or safety rope is warranted, do not take velocity measurements (request SHU unit assistance). When in doubt, err on the side of safety.

9.3 For further field health and safety measures refer to the:Environmental Assessment Program (EAP) Safety Manual

10.0 References

10.1 Model 2000 Portable Flowmeter Instruction Manual. 1990. Marsh-McBirney, Inc. Frederick, MD. www.marsh-mcbirney.com

10.2 Model 201 Portable Flowmeter Instruction Manual. Marsh-McBirney, Inc. Frederick, MD. www.marsh-mcbirney.com

10.3 Model 2100 Instuction Manual. Swoffer Instuments, Inc. Seattle, WA. www.swoffer.com

10.4 Rantz, S.E., et al. Measurement and Computation of Stream Flow. U.S. Geological Survey, Water Supply Paper 2175. http://pubs.usgs.gov/wsp/wsp2175/

10.5 SOP for Measuring Discharge from a Bridge

10.6 SOP for Measuring Discharge from a Boat

Appendix A: Current Meter Instructions

1.0 Current Meter Instructions

1.1 Marsh-McBirney Model 2000

The Marsh-McBirney 2000 consists of a transducer probe cable, and a signal processor. The Marsh-McBirney wading rod has an adapter capable of holding the transducer probe.

Marsh-McBirney model 2000 current meters should be zeroed periodically to ensure accurate measurements. The meters should be zeroed at least once a week during use; however, it is preferable that they are zeroed at the beginning and end of each day of use. They should also be sent to the factory for calibration at least once a year. First clean the sensor because a thin film of oil on the electrodes can cause noisy readings. Then place the sensor in a five gallon plastic bucket of water. Keep it at least three inches away from the sides and bottom of the bucket. To make sure the water is not moving, wait 10 or 15 minutes after you have positioned the sensor before taking any zero readings. Use a filter value of 5 seconds. Zero stability is ± 0.05 ft/sec.

Marsh-McBirney Model 2000 Zero Adjust

- Position the sensor as described in the zero check procedure.
- To initiate the zero start sequence, press the **STO** and **RCL** keys at the same time. You will see the number 3 on the display.
- Decrement to zero with the 6 key.
- The number 32 will be displayed.
- The unit will decrement itself to zero and turn off. The unit is now zeroed.

Measuring Velocity

- Attach transducer to the probe to wading rod.
- Turn the meter on.
- Set selector to desired measuring unit (e.g., FT/S). You can toggle between M/S and FT/S by pressing the **On** and **Off** keys simultaneously. Set the meter to Fixed Point averaging (FPA) and set the interval between 20 and 40 seconds. Press the ↑ and ↓ keys simultaneously to alternate between the FPA and rC displays. The display will show the letters FPA when you first switch to the FPA display. Except for the first period, the display is updated at the end of each averaging period. For example, if the FPA is set to 10 seconds, the display is updated once every ten seconds. The FPA display will have a horizontal time bar under the velocity output. The time bar provides an indication as to the amount of time left until the display is updated. The FPA time is specified in seconds. The ↑ key increments time and the ↓ key decrements time. The display will show the FPA length in seconds. After you have reached the desired setting, wait and the display will automatically switch to velocity.

- Place the probe in the stream with the round end of the sensor facing into the stream.
- The wading rod should be set to the appropriate depth (see Measuring Stream Velocity-Section 6.4).
- Wait for the appropriate time delay and then record the stream velocity.

1.2 Marsh-McBirney Model 201

The Marsh-McBirney 201 consists of a transducer probe cable, and a signal processor. The Marsh-McBirney wading rod has an adapter capable of holding the transducer probe.

Measuring Velocity

- Attach transducer to the probe to wading rod.
- Set selector switch to **Cal** and the time constant switch to **2**. After approximately
  10 seconds, the readout should be on or between 9.8 and 10.2. If not, change the batteries and recheck.
- Set selector to desired measuring unit (e.g., FT/SEC).
- Set time constant switch. The purpose of the time constant is to help stabilize flow readings. This produces a delay between when the unit is first turned on and the time the first full scale reading is reached. This delay can be calculated as seconds by multiplying the switch setting by five. Start with the smallest time constant
  2 (10 second delay). If after the calculated time delay the output has not stabilized, move to the next highest number.
- Place the probe in the stream with the round end of the sensor facing into the stream.
- The wading rod should be set to the appropriate depth (see Measuring Stream Velocity-Section 6.5).
- Wait for the appropriate time delay and then+ record the stream velocity.

1.3 Swoffer Model 2100

The Swoffer is composed of a rotor assembly, sensor body, and cable which are attached to a wading rod (assembly is called the Sensor Wand), an indicator panel then attaches to the Sensor Wand to form the whole unit.

Measuring Velocity

- Turn knob on Swoffer meter to **Calibration**. It should read 185-186. If it is does not, change the nine-volt battery. Record the Calibration # in the proper space in the field notes. Install the propeller on the wading rod and tighten the Allen screw.
- Turn the knob on the Swoffer meter to **Ave. Velocity**.
- Press the **start** button on the Swoffer meter.

- Place the propeller in the stream with the propeller facing into the streamflow.
- Record the velocity in the proper column in the field notes.

Upon completion of the flow measurement, turn the knob on the Swoffer meter to **Calibration** and record the number in the proper space in the field notes.

Appendix D
Standard Operating Procedures for Groundwater Sampling

Ground-Water Sampling Guidelines for Superfund and RCRA Project Managers

GROUND WATER FORUM ISSUE PAPER

Douglas Yeskis* and Bernard Zavala**

BACKGROUND

The Ground Water, Federal Facilities and Engineering Forums were established by professionals from the United States Environmental Protection Agency (USEPA) in the ten Regional Offices. The Forums are committed to the identification and resolution of scientific, technical, and engineering issues impacting the remediation of Superfund and RCRA sites. The Forums are supported by and advise OSWER's Technical Support Project, which has established Technical Support Centers in laboratories operated by the Office of Research and Development (ORD), Office of Radiation Programs, and the Environmental Response Team. The Centers work closely with the Forums providing state-of-the-science technical assistance to USEPA project managers.

This document provides sampling guidelines primarily for ground-water monitoring wells that have a screen or open interval with a length of ten feet or less and which can accept a sampling device. Procedures that minimize disturbance to the aquifer will yield the most representative ground-water samples. This document provides a summary of current and/or recommended ground-water sampling procedures. This document was developed by the Superfund/RCRA Ground Water Forum and incorporates comments from ORD, Regional Superfund hydrogeologists and others. These guidelines are applicable to the majority of sites, but are not intended to replace or supersede regional and/or project-specific sampling plans. These guidelines are intended to assist in developing sampling plans using the project-specific goals and objectives. However, unusual and/or site-specific circumstances may require approaches other than those specified in this document. In these instances, the appropriate Regional hydrologists/geologists should be contacted to establish alternative protocols.

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INTRODUCTION

The goal of ground-water sampling is to collect samples that are “representative” of in-situ ground-water conditions and to minimize changes in ground-water chemistry during sample collection and handling. Experience has shown that ground-water sample collection and handling procedures can be a source of variability in water-quality concentrations due to differences in sampling personnel, sampling procedures, and equipment (U.S. Environmental Protection Agency, 1995).

Several different ground-water sampling procedures can be used, which vary primarily through the criteria used to determine when a sample is representative of ground-water conditions. No single method or procedure is universally applicable to all types of ground-water-sampling programs; therefore, consideration should be given to a variety of factors when determining which method is best suited to site-specific conditions. These site-specific conditions include sampling objectives, equipment availability, site location, and physical constraints. This paper will discuss each of these conditions and how they may contribute to the decision in choosing the appropriate sampling methodology and equipment to be used during ground-water sampling.

This paper focuses on ground-water sampling procedures for monitoring wells only where separate, free-phase, Non-Aqueous Phase Liquids (NAPLs) are not present in the monitoring well. Residential and/or municipal-production wells where special sampling procedures and considerations need to be implemented are not discussed in this document. The recommendations made in this paper are based on findings presented in the current literature, and will be subject to revision as the understanding of ground-water-sampling procedures increases.

SAMPLING OBJECTIVES

The objective of a good sampling program should be the collection of a “representative” sample of the current ground-water conditions over a known or specified volume of aquifer. Ideally to meet this objective, sampling equipment, sampling method, monitoring well construction, monitoring well operation and maintenance, and sample handling procedures should not alter the chemistry of the sample. A sample that is obtained from a poorly constructed well, or using improper sampling equipment, or using poor sampling techniques, or which has been preserved improperly, can bias the sampling results. Unrepresentative samples can lead to misinterpretations of ground-water-quality data. Generally, the costs of obtaining representative ground-water samples are insignificant when compared to potential remedial responses that may be implemented based on erroneous data or when considering the overall monitoring program costs over the life of the program (Nielson, 1991).

The data quality objectives (DQOs) of the sampling program should be thoroughly developed, presented and understood by all parties involved. To develop the DQOs, the purpose of the sampling effort and data use(s) should be clearly defined. The sampling guidelines presented here can be used for a variety of monitoring programs, these include site assessment, contaminant detection, site characterization, remediation, corrective action and compliance monitoring.

For example DQOs for a site characterization sampling effort might vary from those of a remediation monitoring sampling effort. This difference could be in how much of the screen interval should be sampled. A site characterization objective may be to collect a sample that represents a composite of the entire (or as close as is possible) screened interval of the monitoring well. On the other hand, the monitoring objective of a remediation monitoring program may be to obtain a sample that represents a specific portion of the screened interval.

Additionally, the site characterization may require analyses for a broad suite of contaminants, whereas, the remediation monitoring program may require fewer contaminants to be sampled. These differences may dictate the type of sampling equipment used, the type of information collected, and the sampling protocol.

In order to develop applicable DQOs, a site conceptual model should be developed. The site conceptual model should be a dynamic model which is constantly revised as new information is collected and processed. The conceptual model, as it applies to the DQOs, should focus on contaminant fate and transport processes, such as contaminant pathways, how the geologic materials control the contaminant pathways (depositional environments, geologic structure, lithology, etc.), types of contaminants present (i.e., hydrophobic versus hydrophilic), and the processes that influence concentrations of the contaminants present such as dilution, biodegradation, and dispersion. The detail of the conceptual model will depend greatly on the availability of information, such as the number of borings and monitoring wells and the amount of existing analytical data. Clearly, a site that is being investigated for the first time will have a much simpler conceptual model compared to a site that has had a Remedial Investigation, Feasibility Study, and Remedial Design, (or, within the RCRA Program, a RCRA Facility Assessment, a RCRA Facility Investigation, and a Corrective Measures Study), and is currently in remediation/corrective action monitoring. Specific parameters that a conceptual model should describe that may impact the design of a ground-water-sampling program include:

a) The thickness, lateral extent, vertical and horizontal flow direction, and hydraulic conductivity contrasts of the geologic materials controlling contaminant transport from the site (thick units versus thin beds versus fractures, etc.)

b) The types of contaminants to be sampled (volatile organic compounds, semi-volatile organic compounds, metals, etc.) and factors that could bias sampling results (turbidity for metals, co-solvation effects on PCBs, etc.)

c) Lateral and vertical distribution of contamination (contaminants distributed throughout an entire unit being monitored versus localized distribution controlled by small scale features, etc.)

Vertical aquifer characterization is strongly recommended prior to the completion of a ground-water monitoring well installation program. A detailed vertical aquifer characterization program should include field characterization of hydraulic conductivities, determination of vertical and horizontal flow directions, assessment of lithologic and geologic variations, and determination of vertical and horizontal contaminant distributions. The successful aquifer characterization program provides detailed information to guide the technical and cost-effective placement, vertically and areally, of monitoring wells.

INFORMATION NEEDED PRIOR TO SAMPLING

To ensure appropriate methodology and expedient collection of water-quality samples, information is needed before a sample is collected. Some information should be obtained prior to the start of field activities such as well condition, construction, water-level information, contaminant types and concentrations, and direction(s) of ground-water flow. Field measurements, such as depth to water and total well depth will be needed prior to purging. Before commencement of all field activities, the field health and safety plan should be consulted under the direction of the site health and safety officer.

BACKGROUND DATA

Well construction and maintenance information are needed to better plan the sampling program, optimize personnel, and obtain more representative samples. Prior to field activities, personnel should have specific information including well casing diameter, borehole diameter, casing material, lock number and keys, physical access to wells, and length of and depth to well screen. The diameter of each well casing is used to select the correct equipment and technique for purging and sampling the well. A site map with possible physical barriers and description of access is necessary to allow for the selection of proper equipment based on several factors, such as portability, ease of repair, power sources, containment of purge water, and well accessibility. The length and depth of each well screen and depth to water is important when placing a sampling device's intake at the proper depth for purging and sampling and for choosing a sampling device. Well development information is needed to ensure that purging and sampling rates will not exceed well development extraction rates. Previous sampling information should be provided and evaluated to determine the nature and concentrations of expected contaminants. This will be useful in determining the appropriate sampling method and quality assurance/quality control (QA/QC) samples (for example, field duplicates, equipment blanks, trip blanks). Attachment 1 is an example of a sampling checklist for field personnel. This information should be kept in the field for easy access during sampling activities.

When evaluating previous sampling information, consideration should be given to the amount of time that has expired between the last sampling effort and the planned sampling effort. If this time exceeds one year, the need for redevelopment of the monitoring wells should be evaluated. The necessity of redevelopment can be evaluated by measuring constructed depth compared to the measured depth. If the depth measurement indicates siltation of the monitoring well screen, or evidence exists that the well screen is clogged, the well should be redeveloped prior to sampling. The assessment of the condition of the monitoring wells should be completed several weeks prior to sampling activities in order to allow the proper recovery of the developed wells. This is especially important in wells where prior sampling has indicated high turbidity. The time for a well to re-stabilize after development is dependent on site-specific geology and should be specified in the site sampling plan. The development method, if necessary, should be consistent with the sampling objectives, best technical criteria and USEPA guidelines (Aller et al., 1991; Izraeli et al., 1992; Lapham et al., 1997).

REFERENCE POINT

Each well should be clearly marked with a well identifier on the outside and inside of the well casing. Additionally, each well should have a permanent, easily identified reference point from which all depth measurements are taken. The reference point (the top of the inner casing, outer casing, or security/protective casing) should remain constant through all measurements, should be clearly marked on the casing and its description recorded. Whenever possible, the inner casing is recommended as a reference point, because of the general instability of outer casings due to frost heaving, vehicular damage, and other phenomena which could cause movement of casings. The elevation of this reference point should be known and clearly marked at the well site (Nielson, 1991).

This reference point should also have a known latitude and longitude that are consistent with the Regional and National Minimum Data Elements requirements. The elevation of the reference point should be surveyed relative to Mean Sea Level (MSL) using the NAVD 88 datum.

TOTAL WELL DEPTH

The depth of the well is required to calculate the volume of standing water in the well and to document the amount of siltation that may have occurred. Moreover, measuring the depth to the bottom of a well provides checks for casing integrity and for siltation of the well screen. Corrosion can cause leaking or collapse of the well casing, which could lead to erroneous or misleading water-level measurements. Corrosion, silting, and biofouling can clog well screens and result in a sluggish response or no response to water-level changes, as well as changes in ground-water chemistry. Well redevelopment or replacement may be needed to ensure accurate collection of a representative water-quality sample.

Total well depths should be measured and properly recorded to the nearest one-tenth of a foot using a steel tape with a weight attached. The steel tape should be decontaminated before use in another well according to the site specific protocols. A concern is that when the steel tape and weight hit the bottom of the well, sediment present on the bottom of a well may be stirred up, thus increasing turbidity which will affect the sampling results. The frequency of total well depth measurements varies, with no consensus for all hydrogeologic conditions. The United States Geological Survey (USGS) recommends a minimum of once a year (Lapham et al., 1997). USEPA also recommended one measurement per year (Barcelona et al., 1985) but later recommended a total well depth be taken every time a water-quality is collected or a water-level reading taken (Aller et al., 1991). Therefore, when possible, the total depth measurements should be taken following the completion of sampling (Puls and Barcelona, 1996). When total-well-depth measurements are needed prior to sampling, as much time as possible should be allowed prior to sampling, such as a minimum of 24 hours. The weight of electric tapes are generally too light to determine accurate total well depth. If the total well depth is greater than 200 feet, stretching of the tape must be taken into consideration.

DEPTH TO WATER

All water levels should be measured from the reference point by the use of a weighted steel tape and chalk or an electric tape (a detailed discussion of the pros and cons of the different water level devices is provided in Thornhill, 1989). The steel tape is a more accurate method to take water levels, and is recommended where shallow flow gradients (less than 0.05 foot/feet or 0.015 meter/meters) or deep wells are encountered. However, in those cases where large flow gradients or large fluctuations in water levels are expected, a calibrated electric tape is acceptable. The water level is calculated using the well's reference point minus the measured depth to water. At depths approximately greater than 200 feet, the water-level-measuring device should be chosen carefully, as some devices may have measurable stretching.

The depth-to-water measurement must be made in all wells to be sampled prior to activities in any single well which may change the water level, such as bailing, pumping, and hydraulic testing. All readings are to be recorded to the nearest one-hundredth of a foot.

The time and date of the measurement, point of reference, measurement method, depth-to-water level measurement, and any calculations should be properly recorded. In addition, any known, outside influences (such as tidal cycles, nearby pumping effects, major barometric changes) that may affect water levels should be noted.

GROUND-WATER SAMPLING METHODS

The ground-water sampling methods to be employed should be dependent on site-specific conditions and requirements, such as data-quality objectives and well accessibility. Ground-water sampling methods vary based on the type of device used, the position of the sampler intake, the purge criteria used, and the composition of the ground water to be sampled (e.g., turbid, containing high volatile organics, etc.). All sampling methods and equipment should be clearly documented, including purge criteria, field readings, etc. Examples of appropriate documentation are provided in Attachment 2 of this document and Appendix E of the U.S. Environmental Protection Agency, 1995 document.

The water in the screen and filter pack is generally in a constant state of natural flux as ground water passes in and out of the well. However, water above the screened section remains relatively isolated and become stagnant. Stagnant water is subject to physiochemical changes and may contain foreign material, which can be introduced from the surface or during well construction, resulting in non-representative sample data. To safeguard against collecting a sample biased by stagnant water, specific well-purging guidelines and techniques should be followed.

A non-representative sample also can result from excessive pumping of the monitoring well. Stratification of the contaminant concentrations in the aquifer may occur, or heavier-than-water compounds may sink to the lower portions of the aquifer. Excessive pumping can dilute or increase the contaminant concentrations from what is representative of the sampling point.

PURGING AND SAMPLING DEVICES

The device used to purge and sample a well depends on the inner casing diameter, depth to water, volume of water in the well, accessibility of the well, and types of contaminants to be sampled. The types of equipment available for ground-water sampling include hand-operated or motor-driven suction pumps, peristaltic pumps, positive displacement pumps, submersible pumps, various in-situ devices and bailers made of various materials, such as PVC, stainless steel and Teflon®. Some of these devices may cause volatilization and produce high pressure differentials, which could result in variability in the results of pH, dissolved oxygen concentrations, oxidation-reduction potential, specific electrical conductance, and concentrations of metals, volatile organics and dissolved gases. Therefore, the device chosen for well purging and sampling should be evaluated for the possible effects it may have on the chemical and physical analyses. In addition, the types of contaminants, detection levels, and levels of concern as described by the site DQOs should be consulted prior to the selection of a sampling device. The same device used for purging the monitoring well should be used for sampling to minimize agitation of the water column (which can increase turbidity, increase volatilization, and increase oxygen in the water).

In general, the device used for purging and sampling should not change geochemical and physical parameters and/or should not increase turbidity. For this reason, low-flow submersible or positive-displacement pumps that can control flow rates are recommended for purging wells. Dedicated sampling systems are greatly preferred since they avoid the need for decontamination of equipment and minimize turbulence in the well. If a sampling pump is used, the pump should be lowered into the well as slowly as possible and allowed to sit as long as possible, before pumping commences. This will minimize turbidity and volatilization within the well.

Sampling devices (bladders, pumps, bailers, and tubing) should be constructed of stainless steel, Teflon®, glass, and other inert materials to reduce the chance of these materials altering the ground water in areas where concentrations of the site contaminants are expected to be near detection limits. The sample tubing thickness should be maximized and the tubing length should be minimized so that the loss of contaminants through the tubing walls may be reduced and the rate of stabilization of ground-water parameters is maximized. The tendency of organics to sorb into and out of many materials makes the appropriate selection of sample tubing materials critical for these trace analyses (Pohlmann and Alduino, 1992; Parker and Ranney, 1998). Existing Superfund and RCRA guidance suggest appropriate compatible materials (U.S. Environmental Protection Agency, 1992). Special material considerations are important when sampling for non-routine analyses, such as age-dating and biological constituents.

Preferably, wells should be purged and sampled using a positive-displacement pump or a low-flow submersible pump with variable controlled flow rates and constructed of chemically inert materials. If a pump cannot be used because the recovery rate is so slow (less than 0.03 to 0.05 gallons per minute or 100 to 200 milliliters per minute) and the volume of the water to be removed is minimal (less than 5 feet (1.6 meters) of water), then a bailer with a double check valve and bottom-emptying device with a control-flow check valve may be used to obtain the samples. Otherwise, a bailer should not be used when sampling for volatile organics because of the potential bias introduced during sampling (Pohlmann, et al., 1990; Yeskis, et al., 1988; Tai, et al., 1991). A peristaltic pump also may be used under these conditions, unless the bias by a negative pressure may impact the contaminant concentrations of concern (generally at depths greater than 15 to 20 feet (4.5 to 6 meters) of lift). Bailers should also be avoided when sampling for metals due to increased turbidity that occurs during the deployment of the bailer, which may bias inorganic and strongly hydrophobic parameters. Dedicated sampling pumps are recommended for metals sampling because the pumps avoid the generation of turbidity from frequent sampler deployment (Puls et al., 1992). A number of alternate sampling devices are becoming available, including passive diffusion samplers (Vroblesky and Hyde, 1997; Vroblesky, 2001a and b) and other in-situ sampling devices. These devices may be particularly useful to sampling low-permeability geologic materials, assuming the device is made of materials compatible with the analytical parameters, meet DQOs, and have been properly evaluated. However, the site investigator should ensure the diffusion membrane materials are selected for the contaminants of concern (COCs) present at the site. Comparison tests with an approved sampling method and diffusion samplers should be completed to confirm that the method is suitable for the site.

POSITION OF SAMPLE INTAKE

Essentially there are two positions for placement of the sample pump intake, within the screen and above the screen. Each of the positions offers advantages and disadvantages with respect to the portion of the well screen sampled, data reproducibility and potential purge volumes.

When the sampling pump intake is set above the well screen, the pump generally is set just below the water level in the well. The sampling pump then is pumped until a purge criterion is reached (commonly either stabilization of purge parameters or a set number of well volumes). If the distance between the water level and the top of the screen is long, there is concern that the water will be altered geochemically as it flows along the riser pipe, as water flows between the well screen and the sampling pump intake. This is especially a concern if the riser pipe is made of similar material as the COC (such as a stainless steel riser with nickel as a COC, or PVC with organics as a COC). Keely and Boateng (1987) suggested that to minimize this potential influence, the sample pump be lowered gradually while purging, so that at the time of the sampling the pump intake is just above the screen. This would minimize contact time between the ground water and the well construction materials while sampling, as well as ensure the evacuation of the stagnant water above the screen.

With the final location of the sampling pump intake just above the well screen, the sample results may be more reproducible than those collected by positioning the pump intake within the well screen. Results may be more reproducible because the sampler can ensure that the ground water is moving into the well with the same portions of the aquifer being sampled each time assuming the same pump rate. If the pump is placed into different portions of the screen each time, different portions of the aquifer may be sampled. Of course, this can be avoided by the use of dedicated, permanently installed equipment. Additionally, the placement of the pump at the same vertical position within the screen can be ensured by the use of calibrated sampling pump hose, sounding with a weighted tape, or using a pre-measured hose.

The placement of the pump above the screen does not guarantee the water-quality sample represents the entire well screen length. Any bias in the pump placement will be consistently towards the top of the well screen and/or to the zone of highest hydraulic conductivity. Another possible disadvantage, or advantage, depending on the DQOs, of the placement of the pump above the well screen is that the sample may represent a composite of water quality over the well screen. This may result in dilution of a portion of the screen that is in a contaminated portion of an aquifer with another portion that is in an uncontaminated portion of the aquifer. However, shorter well screens would minimize this concern.

When the pump intake is positioned within the well screen, its location is recommended to be opposite the most contaminated zone in the well screen interval. This method is known as the low-flow, low-stress, micropurge, millipurge, or minimal drawdown method. The well is then purged with a minimal drawdown (usually 0.33 feet (0.1 meters) based on Puls and Barcelona, 1996) until selected water-quality-indicator parameters have stabilized. Use of this method may result in the vertical portion of the sampled aquifer being smaller than the well screen length. This method is applicable primarily for short well-screen lengths (less than 5 feet (1.6 meters)) to better characterize the vertical distribution of contaminants (Puls and Barcelona, 1996). This method should not be used with well-screen lengths greater than 10 feet (3 meters). By using this method, the volume of purge water can be reduced, sometimes significantly, over other purging methods.

However, two potential disadvantages of this method exist. The first potential disadvantage may involve the lower reproducibility of the sampling results. The position of the sampling pump intake may vary between sampling rounds (unless adequate precautions are taken to lower the pump into the exact position in previous sampling rounds, or a dedicated system is used), which can result in potentially different zones within the aquifer being sampled. This potential problem can be overcome by using dedicated sampling pumps and the problem may be minimized by the use of short well screens. The second potential disadvantage, or advantage, depending on the DQOs, may be that the sample which is collected may be taken from a small portion of the aquifer volume.

PURGE CRITERIA

“Low-Stress Approach”

The first method for purging a well, known as the low-stress approach, requires the use of a variable-speed, low-flow sampling pump. This method offers the advantage that the amount of water to be containerized, treated, or stored will be minimized. The low-stress method is based on the assumption that pumping at a low rate within the screened zone will not draw stagnant water down, as long as drawdown is minimized during pumping. Drawdown should not exceed 0.33 feet (0.1 meters) (Puls and Barcelona, 1996). The pump is turned on at a low flow rate approximating the estimated recovery rate (based on the drawdown within the monitoring well during sampling). This method requires the location of the pump intake to be within the saturated-screened interval during purging and sampling. The water-quality-indicator parameters (purge parameters), pH, specific electrical conductance, dissolved oxygen concentration, oxidation-reduction potential, temperature and turbidity, are monitored at specific intervals. The specific intervals will depend on the volume within the tubing (include pump and flow-through cell volumes), pump rate and drawdown; commonly every three to five minutes. These parameters should be recorded after a minimum of one tubing volume (include pump and flow-through-cell volumes) has been purged from the well. These water-quality-indicator parameters should be collected by a method or device which prevents air from contacting the sample prior to the reading, such as a flow-through cell (Barcelona et al., 1985; Garske and Schock, 1986; Wilde et al., 1998). Once three successive readings of the water-quality-indicator parameters provided in Table 1 have stabilized, the sampling may begin. The water-quality-indicator parameters that are recommended include pH and temperature, but these are generally insensitive to indicate completion of purging since they tend to stabilize rapidly (Puls and Barcelona, 1996). Oxidation-reduction potential may not always be an appropriate stabilization parameter, and will depend on site-specific conditions. However, readings should be recorded because of its value as a double check for oxidizing conditions, and for some fate and transport issues. When possible, especially when sampling for contaminants that may be biased by the presence of turbidity, the turbidity reading is desired to stabilize at a value below 10 Nephelometric Turbidity Units (NTUs). For final dissolved oxygen measurements, if the readings are less than 1 milligram per liter, they should be collected with the spectrophotometric method (Wilde et al., 1998, Wilkin et al., 2001), colorimetric or Winkler titration (Wilkin et al., 2001). All of these water-quality-indicator parameters should be evaluated against the specifications of the accuracy and resolution of the instruments used.

During purging, water-level measurements must be taken regularly at 30-second to five-minute intervals (depending on the hydraulic conductivity of the aquifer, diameter of the well, and pumping rate) to document the amount of drawdown during purging. The water-level measurements will allow the sampler to control pumping rates to minimize drawdown in the well.

“Well-Volume Approach”

The second method for purging wells is based on proper purging of the stagnant water above the screened interval and the stabilization of water-quality-indicator parameters prior to sampling. Several considerations in this method need to be evaluated before purging. For monitoring wells where the water level is above the screens, the pump should be set near the top of the water column, and slowly lowered during the purging process. For water columns within the well screen, the pump should be set at a sufficient depth below the water level where drawdown during pumping does not allow air to enter the pump. The pump should not be allowed to touch or draw sediments from the bottom of the well, especially when sampling for parameters that may be impacted by turbidity. The well-purging rate should not be great enough to produce excessive turbulence in the well, commonly no greater than one gallon per minute (3.8 liters per minute) in a 2-inch well. The pump rate during sampling should produce a smooth, constant (laminar) flow rate, and should not produce turbulence during the filling of bottles. As a result, the expected flow rate for most wells will be less than one gallon per minute (3.8 liter per minute), with expected flow rates of about one-quarter gallon per minute (500 milliliter per minute).

The stabilization criteria for a “well-volume approach” may be based on the stabilization of water-quality-indicator parameters or on a pre-determined well volume. Various research indicates that purging criteria based on water-quality-indicator parameter stabilization may not always correlate to stabilization of other parameters, such as volatile organic compounds (Gibs and Imbrigiotta, 1990; Puls et al., 1990). A more technically rigorous sampling approach that would yield more consistent results over time would be a time-sequential sampling program at regular well-volume intervals while measuring water-quality-indicator parameters. However, the cost would be prohibitive for most sites. For comparison of water-quality results, by sampling under the same conditions (same purge volume and rate, same equipment, same wells, etc.) temporal evaluations of trends may be considered.

The stabilization requirements of the water-quality-indicator parameters are consistent with those described above for the low-stress approach. The parameters should be recorded approximately every well volume; when three successive readings have reached stabilization, the sample(s) are taken (Barcelona et al., 1985). If a ground-water monitoring well has been sufficiently sampled and characterized (at least several rounds of water-quality samples obtained, including the field parameters, during several seasonal variations), and if water-quality-indicator parameters are no longer needed as a part of site characterization and/or monitoring, then samples could be obtained based on a specific number of well volumes at the previous pumping rates.

LOW-PERMEABILITY FORMATIONS

Different procedures must be followed in the case of slow-recovery wells installed in low hydraulic conductivity aquifers. The following procedures are not optimum, but may be used to obtain a ground-water sample under less than ideal conditions. One suggested procedure is to remove the stagnant water in the casing to just above the top of the screened interval, in a well screened below the water table, to prevent the exposure of the gravel pack or formation to atmospheric conditions (McAlary and Barker, 1987). At no point should the pump be lowered into the screened interval. The pumping rate should be as low as possible for purging to minimize the drawdown in the well. However, if a well has an open interval across the water table in a low permeability zone, there may be no way to avoid pumping and/or bailing a well dry (especially in those cases with four feet of water or less in the well and at a depth to water greater than 20 to 25 feet (which is the practical limit of a peristaltic pump)). In these cases, the well may be purged dry. The sample should be taken no sooner than two hours after purging and after a sufficient volume for a water-quality sample, or sufficient recovery (commonly 90%) is present (Herzog et al., 1988). In these cases, a bailer with a double check valve with a flow-control, bottom-emptying device may be used, since many sampling pumps may have tubing capacities greater than the volume present within the well. If the depth of well and water column are shallow enough, consideration of a very low-flow device, such as a peristaltic pump, should be considered, especially if constituents are present that are not sensitive to negative pressures that may be created with the use of the peristaltic pump. If such constituents are present and sampled with a peristaltic pump, a negative bias may be introduced into the sampling results. To minimize the bias, thick-walled, non-porous tubing should be used, except for a small section in the pump heads, which require a greater degree of flexibility. As stated earlier in this paper, the DQOs for the sampling should be consulted to consider the potential impact of the sampling device on the potential bias versus the desired detection levels.

Another method to be considered for low-permeability conditions is the use of alternative sampling methods, such as passive diffusion samplers and other in-situ samplers. As more sites are characterized with these alternative sampling methods and devices, the potential bias, if any, can be evaluated with regard to the sampling DQOs. Regional hydrologists/geologists and Regional quality-assurance specialists should be consulted on the applicability of these methods for the site-specific conditions.

DECISION PROCESS FOR DETERMINING APPLICABLE SAMPLING METHODOLOGY

Once the project team has determined the sampling objectives and DQOs, reviewed the existing data, and determined the possible sampling devices that can be used, the team must decide the appropriate sampling methodology to be used. Table 2 provides a summary of considerations and rationale to be used in establishing the proper ground-water-sampling program using site-specific conditions and objectives.

POTENTIAL PROBLEMS

The primary objective is to obtain a sample representative of the ground water moving naturally (including both dissolved and particulate species) through the subsurface. A ground-water sample can be compromised by field personnel in two primary ways: taking an unrepresentative sample and handling the (representative) sample incorrectly. There are numerous ways of introducing foreign contaminants into a sample. These must be avoided by following strict sampling protocols and transportation procedures, and utilizing trained personnel. Common problems with sampling include the use of inappropriate sample containers and field composites, and the filtration of turbid samples.

SAMPLE CONTAINERS

Field samples must be transferred from the sampling equipment to the container that has been specifically prepared for that given parameter. Samples must not be composited in a common container in the field and then split in the lab. The USEPA Regional policy on sample containers should be consulted to determine the appropriate containers for the specified analysis.

FIELD FILTRATION OF TURBID SAMPLES

The USEPA recognizes that in some hydrogeologic environments, even with proper well design, installation, and development, in combination with the low-flow purging and sampling techniques, sample turbidity cannot be reduced to ambient levels. The well construction, development, and sampling information should be reviewed by the Regional geologists or hydrologists to see if the source of the turbidity problems can be resolved or if alternative sampling methodologies should be employed. If the water sample is excessively turbid, the collection of both filtered and unfiltered samples, in combination with turbidity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), pumping rate, and drawdown data is recommended. The filter size used to determine TSS and TDS should be the same as used in the field filtration. An in-line filter should be used to minimize contact with air to avoid precipitation of metals. The typical filter media size used is 0.45 µm because this is commonly accepted as the demarcation between dissolved and non-dissolved species. Other filter sizes may be appropriate but their use should be determined based on site-specific criteria (examples include grain-size distribution, ground-water-flow velocities, mineralogy) and project DQOs. Filter sizes up to 10.0 µm may be warranted because larger size filters may allow particulates that are mobile in ground water to pass through (Puls and Powell, 1992). The changing of filter media size may limit the comparability of the data obtained with other data sets and may affect their use in some geochemical models. Filter media size used on previous data sets from a site, region or aquifer and the DQOs should be taken into consideration. The filter media used during the ground-water sampling program should be collected in a suitable container and archived because potential analysis of the media may be helpful for the determination of particulate size, mineralogy, etc.

The first 500 to 1000 milliliters of a ground-water sample (depending on sample turbidity) taken through the in-line filter will not be collected for a sample in order to ensure that the filter media has equilibrated to the sample (manufacturer's recommendations also should be consulted). Because bailers have been shown to increase turbidity while purging and sampling, bailers should be avoided when sampling for trace element, metal, PCB, and pesticide constituents. If portable sampling pumps are used, the pumps should be gently lowered to the sampling depth desired, carefully avoiding lowering it to the bottom of the well, and allowed to sit in order to allow any particles mobilized by pump placement to settle. Dedicated sampling equipment installed in the well prior to the commencement of the sampling activities is one of the recommended methods to reduce turbidity artifacts (Puls and Powell, 1992; Kearl et al., 1992; Puls et al., 1992; Puls and Barcelona, 1996).

SAMPLER DECONTAMINATION

The specific decontamination protocol for sampling devices is dependent on site-specific conditions, types of equipment used and the types of contaminants encountered. Once removed from the well, non-dedicated sampling equipment should be decontaminated to help ensure that there will be no cross-contamination between wells. Disposable items such as rope and low-grade tubing should be properly disposed between wells. Cleaning thoroughly that portion of the equipment that is going to come into contact with well water is especially important. In addition, a clean plastic sheet should be placed adjacent to or around the well to prevent surface soils from coming in contact with the purging and sampling equipment. The effects of cross-contamination can be minimized by sampling the least contaminated well first and progressing to the more contaminated ones. Equipment blanks should be collected on a regular basis from non-dedicated equipment, the frequency depending on the sampling plan and regional protocols, to document the effectiveness of the decontamination procedures.

The preferred method is to use dedicated sampling equipment whenever possible. Dedicated equipment should still be cleaned on a regular basis to reduce biofouling, and to minimize adsorption effects. Dedicated equipment should have equipment blanks taken after every cleaning.

POST-SAMPLING ACTIVITIES

Specific activities should be completed at monitoring wells at regular intervals to ensure the acquisition of representative ground-water samples. Activities include hydraulic conductivity testing to determine if a monitoring well needs redeveloping and/or replacing. Another activity that needs to be completed is regular surveying of well measuring points impacted by frost heaving and site activities. The schedules of these activities are to be determined on a site-by-site basis in consultation with regional geologists or hydrologists, but at a minimum, should be every five years.

CONCLUSION

This document provides a brief summary of the state-of-the-science to be used for Superfund and RCRA ground-water studies. As additional research is completed, additional sampling experience with other sampling devices and methods and/or additional contaminants are identified, this paper may be revised to include the new information/concerns. Clearly there is no one sampling method that is applicable for all sampling objectives. As new methods and/or equipment are developed, additional standard operating procedures (SOPs) should be developed and attached to this document. These SOPs for ground-water sampling should include, at a minimum: introduction, scope and application, equipment, purging and sampling procedures, field quality control, decontamination procedures and references. Example SOP’s for the low-stress/minimal-drawdown and well-volume sampling procedures have been included as Attachments 3 and 4. These example SOPs are to be considered a pattern or starting point for site-specific ground-water-sampling plans. A more detailed discussion of sampling procedures, devices, techniques, etc. is provided in various publications by the USEPA (Barcelona et al., 1985; U.S. Environmental Protection Agency, 1993) and the U.S. Geological Survey (Wilde et al., 1998).

REFERENCES

Aller, L., T.W. Bennett, G. Hackett, R.J. Petty, J.H. Lehr, H. Sedoris, D.M. Nielson and J.E. Denne, 1991, Handbook of Suggested Practices for the Design and Installation of Ground-Water Monitoring Wells; U.S. Environmental Protection Agency, EPA/600/4-89/034, 221 pp.

Barcelona, M.J., J.P. Gibb, J.A. Hellfrich, and E.E. Garske, 1985, Practical Guide for Ground-Water Sampling; U.S. Environmental Protection Agency, EPA/600/2-85/104, 169 pp.

Garske, E.E., and M.R. Schock, 1986, An Inexpensive Flow-Through Cell and Measurement System for Monitoring Selected Chemical Parameters in Ground Water; Ground Water Monitoring Review, Vol. 6, No. 3, pp. 79-84.

Gibs, J. and T.E. Imbrigiotta, 1990, Well-Purging Criteria for Sampling Purgeable Organic Compounds; Ground Water, Vol. 28, No. 1, pp.68-78.

Herzog, B.L., S.J. Chou, J.R. Valkenburg and R.A. Griffin, 1988, Changes in Volatile Organic Chemical Concentrations After Purging Slowly Recovering Wells; Ground Water Monitoring Review, Vol. 8, No. 4, pp. 93-99.

Izraeli, R., D. Yeskis, M. Collins, K. Davies and B. Zavala, 1992, GROUND WATER ISSUE PAPER: Monitoring Well Development Guidelines for Superfund Project Managers; U.S. Environmental Protection Agency, 4 pp.

Kearl, P.M., N.E. Korte, and T.A. Cronk, 1992, Suggested Modifications to Ground Water Sampling Procedures Based on Observations from the Colloid Borescope; Ground Water Monitoring Review, Vol. 12, No. 2, pp. 155-161.

Keely, J.F. and K. Boateng, 1987, Monitoring well Installation, Purging, and Sampling Techniques - Part 1: Conceptualizations; Ground Water, Vol. 25, No. 4, pp. 427-439.

Lapham, W.W., F.D. Wilde and M.T. Koterba, 1997, Guidelines and Standard Procedures for Studies of Ground-Water Quality: Selection and Installation of Wells, and Supporting Documentation; U.S. Geological Survey Water-Resources Investigations Report 96-4233, 110 pp.

McAlary, T.A. and J.F. Barker, 1987, Volatilization Losses of Organics During Ground Water Sampling from Low Permeability Materials; Ground Water Monitoring Review, Vol. 7, No. 4, pp. 63-68.

Nielson, D.M., 1991, Practical Handbook of Ground-Water Monitoring; Lewis Publishers, 717 pp.

Parker, L.V. and T.A. Ranney, 1998, Sampling Trace-Level Organic Solutes with Polymeric Tubing: Part 2, Dynamic Studies; Ground Water Monitoring and Remediation, Vol. 18, No. 1, pp. 148-155.

Pohlmann, K.F., R.P. Blegen, and J.W. Hess, 1990, Field Comparison of Ground-Water Sampling Devices for Hazardous Waste Sites: An Evaluation using Volatile Organic Compounds; U.S. Environmental Protection Agency, EPA/600/4-90/028, 102 pp.

Pohlmann, K.F. and A.J. Alduino, 1992, GROUND-WATER ISSUE PAPER: Potential Sources of Error in Ground-Water Sampling at Hazardous Waste Sites; U.S. Environmental Protection Agency, EPA/540/S-92/019.

Puls, R.W., J.H. Eychaner, and R.M. Powell, 1990, ENVIRONMENTAL RESEARCH BRIEF: Colloidal-Facilitated Transport of Inorganic Contaminants in Ground Water: Part I. Sampling Considerations; U.S. Environmental Protection Agency, EPA/600/M-90/023, 12 pp.

Puls, R.W. and R.M. Powell, 1992, Acquisition of Representative Ground Water Quality Samples for Metals; Ground Water Monitoring Review, Vol. 12, No. 3, pp. 167-176.

Puls, R.W., D.A. Clark, B. Bledsoe, R.M. Powell and C.J. Paul, 1992, Metals in Ground Water: Sampling Artifacts and Reproducibility; Hazardous Waste and Hazardous Materials, Vol. 9, No. 2, pp. 149-162.

Puls, R.W. and M.J. Barcelona, 1996, GROUND-WATER ISSUE PAPER: Low-Flow (Minimal Draw-down) Ground-Water Sampling Procedures; U.S. Environmental Protection Agency, EPA/540/S-95/504, 12 pp.

Tai, D.Y., K.S. Turner, and L.A. Garcia, 1991, The Use of a Standpipe to Evaluate Ground Water Samples; Ground Water Monitoring Review, Vol. 11, No. 1, pp. 125-132.

Thornhill, J.T., 1989, GROUND-WATER ISSUE PAPER: Accuracy of Depth to Water Measurements; U.S. Environmental Protection Agency, EPA/540/4-89/002, 3 pp.

U.S. Environmental Protection Agency, 1992, RCRA Ground-Water Monitoring: Draft Technical Guidance; EPA/530-R-93-001.

U.S. Environmental Protection Agency, 1993, Subsurface Characterization and Monitoring Techniques: A Desk Reference Guide: Volume I: Solids and Ground Water Appendices A and B; EPA/625/R-93/003a.

U.S. Environmental Protection Agency, 1995, Ground Water Sampling - A Workshop Summary, Dallas, Texas, November 30-December 2, 1993; EPA/600/R-94/205, 146 pp.

Vroblesky, D.A., 2001a, User's Guide for Polyethylene-Based Passive Diffusion Bag Samplers to Obtain Volatile Organic Compound Concentrations in Wells, Part 1: Deployment, Recovery, Data Interpretation, and Quality Control and Assurance; U.S. Geological Survey Water-Resources Investigations Report 01-4060,
18 pp.

Vroblesky, D.A. ed., 2001b, User's Guide for Polyethylene-Based Passive Diffusion Bag Samplers to Obtain Volatile Organic Compound Concentrations in Wells, Part 2: Field Tests; U.S. Geological Survey Water-Resources Investigations Report 01-4061, variously paginated.

Vroblesky, D.A. and Hyde, W.T., 1997, Diffusion Samplers as an Inexpensive Approach to Monitoring VOCs in Ground Water; Ground Water Monitoring and Remediation, Vol. 17, No. 3, pp. 177-184.

Wilde, F.D., D.B. Radtke, J.Gibs and R.T. Iwatsubo, eds., 1998, National Field Manual for the Collection of Water-Quality Data; U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9, Handbooks for Water-Resources Investigations, variously paginated.

Wilkin, R.T., M.S. McNeil, C.J. Adair and J.T. Wilson, 2001, Field Measurement of Dissolved Oxygen: A Comparison of Methods, Ground Water Monitoring and Remediation, Vol. 21, No. 4, pp. 124-132.

Yeskis, D., K. Chiu, S. Meyers, J. Weiss, and T. Bloom, 1988, A Field Study of Various Sampling Devices and Their Effects on Volatile Organic Contaminants; Proceedings of the Second National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods, National Water Well Association, May 1988.

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TABLES:

Stablization Criteria with References for Water-Quality-Indicator Parameters

and

Applicability of Different Approaches for Purging and Sample Monitoring Wells

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TABLE 1: Stabilization Criteria with References for Water-Quality-Indicator Parameters

Parameter	Stabilization Criteria	Reference
pH	+/- 0.1	Puls and Barcelona, 1996; Wilde et al., 1998
specific electrical conductance (SEC)	+/- 3%	Puls and Barcelona, 1996
oxidation-reduction potential (ORP)	+/- 10 millivolts	Puls and Barcelona, 1996
turbidity	+/- 10% (when turbidity is greater than 10 NTUs)	Puls and Barcelona, 1996; Wilde et al., 1998
dissolved oxygen (DO)	+/- 0.3 milligrams per liter	Wilde et al., 1998

TABLE 2: Applicability of Different Approaches for Purging and Sampling Monitoring Wells

	Low-Stress Approach	**Well-Volume Approach**	**Others** (such as passive diffusion samplers, in-situ samplers, and other non-traditional ground-water sampling pumps)
Applicable Geologic Materials[1]	Materials with moderate to high hydraulic conductivities. May be applicable to some low hydraulic conductivities, if can meet minimal drawdown criteria.	Materials with low to high hydraulic conductivities	Materials with very low to high hydraulic conductivities
Aquifer/Plume Characterization Data Needs prior to Choosing Sampling Method [2]	High definition of vertical hydraulic conductivity distribution and vertical contaminant distribution	Plume and hydraulic conductivity distributions are less critical	May need to consider the degree of hydraulic and contaminant vertical distribution definition dependent on Data Quality Objectives and sampler type.
Constituent Types Method is Applicable	Mainly recommended for constituents which can be biased by turbidity in wells. Applicable for most other contaminants.	Applicable for all sampling parameters. However, if turbidity values are elevated, low-stress approach may be more applicable if constituents of concern are turbidity sensitive.	Constituents of concern will be dependent on the type of sampler.
Data Quality Objectives	1) High resolution of plume definition both vertically and horizontally. 2) Reduce bias from other sampling methods if turbidity is of concern. 3) Target narrow sections of aquifer.	1) Basic site characterization 2) Moderate to high resolution of plume definition (will be dependent on screen length). 3) Target sample composition to represent entire screened/open interval	1) Can be applicable to basic site characterization, depending on sampler and methodology used. 2) Can reduce bias from other sampling methods. 3) May yield high resolution of plume definition.

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[1] Hydraulic conductivities of aquifer materials vary from low hydraulic conductivities (clays, silts, very fine sands) to high conductivities (gravels, sands, weathered bedrock zones). This term for the use on this table is subjective, and is more dependent on the drawdown induced in a monitoring well when sampled with a ground-water sampling pump. For instance, in a well being pumped at 4 liters per minute (l/min) with less than 0.1 feet of drawdown, can be considered to have high hydraulic conductivity. A well that can sustain a 0.2 to 0.4 l/min pumping rate, but has more than 0.5 feet of drawdown can be considered to have low hydraulic conductivity. To assign absolute values of hydraulic conductivities to well performance and sustainable pumping rates cannot be completed because of the many factors in monitoring well construction, such as well diameter, screen open area, and length of screen.

[2] See last paragraph under the SAMPLING OBJECTIVES section.

ATTACHMENT 1
Example Sampling Checklist

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SAMPLING CHECKLIST

Well Identification:________________________

Map of Site Included: Y or N
Wells Clearly Identified with Roads: Y or N
Well Construction Diagram Attached: Y or N

Well Construction:

Diameter of Borehole:________ Diameter of Casing:__________
Casing Material:____________ Screen Material:______________
Screen Length:_____________ Total Depth:______________

Approximate Depth to Water:_____________
Maximum Well Development Pumping Rate:_________________
Date of Last Well Development:_____________

Previous Sampling Information:

Was the Well Sampled Previously: Y or N
(If Sampled, Fill Out Table Below)

Table of Previous Sampling Information

Parameter	Previously Sampled	Number of Times Sampled	Maximum Concentration	Notes (include previous purge rates)

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ATTACHMENT 2
Example Ground-Water Sampling Field Sheets

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GROUND-WATER SAMPLING RECORD

Well ID:______________

Station #:_____________

Facility Name:

Date:____/____/____

Well Depth:__________ Depth to Water:__________ Well Diameter:___________

Casing Material.:__________ Volume Of Water per Well Volume:______________

Sampling Crew:_________________,___________________,__________________,_____________________

Type of Pump:_________ ___________ Tubing Material:__________________ Pump set at _________________ ft.

Weather Conditions:_________________________________ NOTES:_________ ________________________

GROUND-WATER SAMPLING PARAMETERS

Time	Water Level	Volume Pumped	Pumping Rate	DO (mg/l)	Temp. (^{0}C)	SEC (µS/cm)	pH	ORP (mV)	Turbidity (NTU)

Other Parameters: ___________________

Sampled at:_______________ Parameters taken with :____

Sample delivered to ______________________________ by ____________________________ at___________.

Sample CRL #:______________ OTR #:______________ ITR #:______________ SAS #:_________________

Parameters Collected	Number of Bottles	Bottle Lot Number

Ground Water Sampling Log

Site Name: **Well #:** **Date:**
Well Depth(Ft-BTOC[1]): **Screen Interval**(Ft):

Well Dia.: **Casing Material:** **Sampling Device:**

Pump placement(Ft from TOC[2]):

Measuring Point: **Water level (static)**(Ft):

Water level (pumping)(Ft): **Pump rate**(Liter/min):

Sampling Personnel:

Other info: (such as sample numbers, weather conditions and field notes)

Water Quality Indicator Parameters

Time	Pumping rates (L/Min)	Water level (ft)	DO (mg/L)	ORP (mv)	SEC[3]	Turb. (NTU)	pH	Temp. (C^0)	Volume pumped (L)

Type of Samples collected:

1 casing volume was:
Total volume purged prior to sample collection:

Stabilization Criteria

D.O.	+/- 0.3 mg/l
Turb.	+/- 10%
S.C.	+/- 3%
ORP	+/- 10 mV
pH	+/- 0.1 unit

[1] BTOC-Below Top of Casing
[2] TOC-Top of Casing
[3] Specific Electrical Conductance

ATTACHMENT 3
Example Standard Operating Procedure:

Standard Operating Procedure for
Low-Stress (Low Flow)/Minimal Drawdow
Ground-Water Sample Collection

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Standard Operating Procedure for Low-Stress (Low-Flow)/ Minimal Drawdown Ground-Water Sample Collection

INTRODUCTION

The collection of “representative” water samples from wells is neither straightforward nor easily accomplished. Ground-water sample collection can be a source of variability through differences in sample personnel and their individual sampling procedures, the equipment used, and ambient temporal variability in subsurface and environmental conditions. Many site inspections and remedial investigations require the sampling at ground-water monitoring wells within a defined criterion of data confidence or data quality, which necessitates that the personnel collecting the samples are trained and aware of proper sample-collection procedures.

The purpose of this standard operating procedure (SOP) is to provide a method that minimizes the impact the purging process has on the ground-water chemistry and the volume of water that is being purged and disposed of during sample collection. This will take place by placing the pump intake within the screen interval and by keeping the drawdown at a minimal level (0.33 feet) (Puls and Barcelona, 1996) until the water quality parameters have stabilized and sample collection is complete. The flow rate at which the pump will be operating will depend upon both hydraulic conductivity of the aquifer and the drawdown with the goal of minimizing the drawdown. The flow rate from the pump during purging and sampling will be at a rate that will not compromise the integrity of the analyte that is being sampled. This sampling procedure may or may not provide a discrete ground-water sample at the location of the pump intake. The flow of ground-water to the pump intake will be dependent on the distribution of the hydraulic conductivity (K) of the aquifer within the screen interval. In order to minimize the drawdown in the monitoring well, a low-flow rate must be used. “Low-Flow” refers to the velocity with which water enters the pump intake from the surrounding formation 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 (Puls and Barcelona, 1996). This SOP was developed by the Superfund/RCRA Ground Water Forum and draws from an USEPA’s Ground Water Issue Paper, Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedure, by Robert W. Puls and Michael J. Barcelona. Also, available USEPA Regional SOPs regarding Low-Stress (Low-Flow) Purging and Sampling were used for this SOP.

SCOPE AND APPLICATION

This SOP should be used primarily at monitoring wells that have a screen or an open interval with a length of ten feet or less and can accept a sampling device that minimizes the disturbance to the aquifer or the water column in the well casing. The screen or open interval should have been optimally located to intercept an existing contaminant plume(s) or along flowpaths of potential contaminant releases. Knowledge of the contaminant distribution within the screen interval is highly recommended and is essential for the success of this sampling procedure. The ground-water samples that are collected using this procedure are acceptable for the analyses of ground-water contaminants that may be found at Superfund and RCRA contamination sites. The analytes may be volatile, semi-volatile organic compounds, pesticides, PCBs, metals, and other inorganic compounds. The screened interval should be located within the contaminant plume(s) and the pump intake should be placed at or near the known source of the contamination within the screened interval. It is critical to place the pump intake in the exact location or depth for each sampling event. This argues for the use of dedicated, permanently installed, sampling devices whenever possible. If this is not possible, then the placement of the pump intake should be positioned with a calibrated sampling pump hose sounded with a weighted-tape or using a pre-measured hose. The pump intake should not be placed near the bottom of the screened interval to avoid disturbing any sediment that may have settled at the bottom of the well.

Water-quality-indicator parameters and water levels must be measured during purging, prior to sample collection. Stabilization of the water-quality-indicator parameters as well as monitoring water levels are a prerequisite to sample collection. The water-quality-indicator parameters that are recommended include the following: specific electrical conductance, dissolved oxygen, turbidity, oxidation-reduction potential, pH, and temperature. The latter two parameters are useful data, but are generally insensitive as purging parameters. Oxidation-reduction potential may not always be appropriate stabilization parameter, and will depend on site-specific conditions. However, readings should be recorded because of its value as a double check for oxidation conditions and for fate and transport issues.

Also, when samples are collected for metals, semivolatile organic compounds, and pesticides, every effort must be made to reduce turbidity to 10 NTUs or less (not just the stabilization of turbidity) prior to the collection of the water sample. In addition to the measurement of the above parameters, depth to water must be measured during purging (U.S. Environmental Protection Agency, 1995).

Proper well construction, development, and maintenance are essential for any ground-water sampling procedure. Prior to conducting the field work, information on the construction of the well and well development should be obtained and that information factored into the site specific sampling procedure. The Sampling Checklist at the end of this attachment is an example of the type of information that is useful.

Stabilization of the water-quality-indicator parameters is the criterion for sample collection. But if stabilization is not occurring and the procedure has been strictly followed, then sample collection can take place once three (minimum) to six (maximum) casing volumes have been removed (Schuller et al., 1981 and U.S. Environmental Protection Agency., 1986; Wilde et al., 1998; Gibs and Imbrigiotta., 1990). The specific information on what took place during purging must be recorded in the field notebook or in the ground-water sampling log.

This SOP is not to be used where non-aqueous phase liquids (NAPL) (immiscible fluids) are present in the monitoring well.

EQUIPMENT

- Depth-to-water measuring device - An electronic water-level indicator or steel tape and chalk, with marked intervals of 0.01 foot. Interface probe for determination of liquid products (NAPL) presence, if needed.
- Steel tape and weight - Used for measuring total depth of well. Lead weight should not be used.
- Sampling pump - Submersible or bladder pumps with adjustable rate controls are preferred. Pumps are to be constructed of inert materials, such as stainless steel and Teflon®. Pump types that are acceptable include gear and helical driven, centrifugal (low-flow type), and air-activated piston. An adjustable rate, peristaltic pump can be used when the depth to water is 20 feet or less.
- Tubing - Teflon® or Teflon®-lined polyethylene tubing is preferred when sampling for organic compounds. Polyethylene tubing can be used when sampling inorganics.
- Power source - If a combustion type (gasoline or diesel-driven) generator is used, it must be placed downwind of the sampling area.
- Flow measurement supplies - flow meter, graduated cylinder, and a stop watch.
- Multi-parameter meter with flow-through cell - This can be one instrument or more contained in a flow-through cell. The water-quality-indicator parameters that are monitored are pH, ORP/Eh, (ORP) dissolved oxygen (DO), turbidity, specific conductance, and temperature. Turbidity readings must be collected before the flow cell because of the potential for sediment buildup, which can bias the turbidity measurements. Calibration fluids for all instruments should be NIST-traceable and there should be enough for daily calibration throughout the sampling event. The inlet of the flow cell must be located near the bottom of the flow cell and the outlet near the top. The size of the flow cell should be kept to a minimum and a closed cell is preferred. The flow cell must not contain any air or gas bubbles when monitoring for the water-quality-indicator parameters.
- Decontamination supplies - Including a reliable and documented source of distilled water and any solvents (if used). Pressure sprayers, buckets or decontamination tubes for pumps, brushes and non-phosphate soap will also be needed.
- Sample bottles, sample preservation supplies, sample tags or labels, and chain-of-custody forms.
- Approved Field Sampling and Quality Assurance Project Plan.
- Well construction, field, and water quality data from the previous sampling event.
- Well keys and map of well locations.
- Field notebook, ground-water sampling logs, and calculator. A suggested field data sheet (ground-water sampling record or ground-water sampling log) are provided at the end of this attachment.

- Filtration equipment, if needed. An in-line disposable filter is recommended.
- Polyethylene sheeting placed on ground around the well head.
- Personal protective equipment as specified in the site Health and Safety Plan.
- Air monitoring equipment as specified in the Site Health and Safety Plan.
- Tool box - All needed tools for all site equipment used.
- A 55-gallon drum or container to contain the purged water.

Construction materials of the sampling equipment (bladders, pumps, tubing, and other equipment that comes in contact with the sample) should be limited to stainless steel, Teflon®, glass, and other inert material. This will reduce the chance that sampling materials alter the ground-water where concentrations of the site contaminants are expected to be near the detection limits. The sample tubing diameter should be maximized and the tubing length should be minimized so that the loss of contaminants into and through the tubing walls may be reduced and the rate of stabilization of ground-water parameters is maximized. The tendency of organics to sorb into and out of material makes the appropriate selection of sample tubing material critical for trace analyses (Pohlmann and Alduino, 1992; Parker and Ranney, 1998).

PURGING AND SAMPLING PROCEDURES

The following describes the purging and sampling procedures for the Low-Stress (Low-Flow)/ Minimal Drawdown method for the collection of ground-water samples. These procedures also describe steps for dedicated and non-dedicated systems.

Pre-Sampling Activities (Non-dedicated and dedicated system)

1. Sampling must begin at the monitoring well with the least contamination, generally up-gradient or farthest from the site or suspected source. Then proceed systematically to the monitoring wells with the most contaminated ground water.

2. Check and record the condition of the monitoring well for damage or evidence of tampering. Lay out polyethylene sheeting around the well to minimize the likelihood of contamination of sampling/purging equipment from the soil. Place monitoring, purging and sampling equipment on the sheeting.

3. Unlock well head. Record location, time, date, and appropriate information in a field logbook or on the ground-water sampling log (See attached ground-water sampling record and ground-water sampling log as examples).

4. Remove inner casing cap.

5. Monitor the headspace of the monitoring well at the rim of the casing for volatile organic compounds (VOC) with a photo-ionization detector (PID) or flame ionization detector (FID) and record in the logbook. If the existing monitoring well has a history of positive readings of the headspace, then the sampling must be conducted in accordance with the Health and Safety Plan.

6. Measure the depth to water (water level must be measured to nearest 0.01 feet) relative to a reference measuring point on the well casing with an electronic water level indicator or steel tape and record in logbook or ground-water sampling log. If no reference point is found, measure relative to the top of the inner casing, then mark that reference point and note that location in the field logbook. Record information on depth to ground water in the field logbook or ground-water sampling log. Measure the depth to water a second time to confirm initial measurement; measurement should agree within 0.01 feet or re-measure.

7. Check the available well information or field information for the total depth of the monitoring well. Use the information from the depth of water in step six and the total depth of the monitoring well to calculate the volume of the water in the monitoring well or the volume of one casing. Record information in field logbook or ground-water sampling log.

Purging and Sampling Activities

8A. Non-dedicated system - Place the pump and support equipment at the wellhead and slowly lower the pump and tubing down into the monitoring well until the location of the pump intake is set at a predetermined location within the screen interval. The placement of the pump intake should be positioned with a calibrated sampling pump hose, sounded with a weighted-tape, or using a pre-measured hose. Refer to the available monitoring well information to determine the depth and length of the screen interval. Measure the depth of the pump intake while lowering the pump into location. Record pump location in field logbook or ground-water sampling log.

8B. Dedicated system - Pump has already been installed, refer to the available monitoring well information and record the depth of the pump intake in the field logbook or ground-water sampling log.

9. Non-dedicated system and dedicated systems - Measure the water level (water level must be measured to nearest 0.01 feet) and record information on the ground-water sampling log, leave water level indicator probe in the monitoring well.

10. Non-dedicated and dedicated systems - Connect the discharge line from the pump to a flow-through cell. A "T" connection is needed prior to the flow-through cell to allow for the collection of water for the turbidity measurements. The discharge line from the flow-through cell must be directed to a container to contain the purge water during the purging and sampling of the monitoring well.

11. Non-dedicated and dedicated systems - Start pumping the well at a low flow rate (0.2 to 0.5 liter per minute) and slowly increase the speed. Check water level. Maintain a steady flow rate while maintaining a drawdown of less than 0.33 feet (Puls and Barcelona, 1996). If drawdown is greater than 0.33 feet, lower the flow rate. 0.33 feet is a goal to help guide with the flow rate adjustment. It should be noted that 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 (Puls and Barcelona, 1996).

12. Non-dedicated and dedicated systems - Measure the discharge rate of the pump with a graduated cylinder and a stop watch. Also, measure the water level and record both flow rate and water level on the ground-water sampling log. Continue purging, monitor and record water level and pump rate every three to five minutes during purging. Pumping rates should be kept at minimal flow to ensure minimal drawdown in the monitoring well.

13. Non-dedicated and dedicated systems - During the purging, a minimum of one tubing volume (including the volume of water in the pump and flow cell) must be purged prior to recording the water-quality indicator parameters. Then monitor and record the water-quality- indicator parameters every three to five minutes. The water-quality indicator field parameters are turbidity, dissolved oxygen, specific electrical conductance, pH, redox potential, and temperature. Oxidation-reduction potential may not always be an appropriate stabilization parameter, and will depend on site-specific conditions. However, readings should be recorded because of its value as a double check for oxidizing conditions. Also, for the final dissolved oxygen measurement, if the readings are less than 1 milligram per liter, it should be collected and analyze with the spectrophotometric method (Wilde et al., 1998 Wilkin et al., 2001), colorimetric or Winkler titration (Wilkin et al., 2001). The stabilization criterion is based on three successive readings of the water quality field parameters; the following are the criteria which must be used:

Parameter	Stabilization Criteria	Reference
pH	+/- 0.1 pH units	Puls and Barcelona, 1996; Wilde et al., 1998
specific electrical conductance (SEC)	+/- 3% S/cm	Puls and Barcelona, 1996
oxidation-reduction potential (ORP)	+/- 10 millivolts	Puls and Barcelona, 1996
turbidity	+/- 10% NTUs (when turbidity is greater than 10 NTUs)	Puls and Barcelona, 1996; Wilde et al., 1998
dissolved oxygen	+/- 0.3 milligrams per liter	Wilde et al., 1998

Once the criteria have been successfully met indicating that the water quality indicator parameters have stabilized, then sample collection can take place.

14. If a stabilized drawdown in the well can't be maintained at 0.33 feet and the water level is approaching the top of the screened interval, reduce the flow rate or turn the pump off (for 15 minutes) and allow for recovery. It should be noted whether or not the pump has a check valve. A check valve is required if the pump is shut off. Under no circumstances should the well be pumped dry. Begin pumping at a lower flow rate, if the water draws down to the top of the screened interval again, turn pump off and allow for recovery. If two tubing volumes (including the volume of water in the pump and flow cell) have been removed during purging, then sampling can proceed next time the pump is turned on. This information should be noted in the field notebook or ground-water sampling log with a recommendation for a different purging and sampling procedure.

15. Non-dedicated and dedicated systems - Maintain the same pumping rate or reduce slightly for sampling (0.2 to 0.5 liter per minute) in order to minimize disturbance of the water column. Samples should be collected directly from the discharge port of the pump tubing prior to passing through the flow-through cell. Disconnect the pump's tubing from the flow-through cell so that the samples are collected from the pump's discharge tubing. For samples collected for dissolved gases or VOC analyses, the pump tubing needs to be completely full of ground water to prevent the ground water from being aerated as it flows through the tubing. The sequence of the samples is immaterial unless filtered (dissolved) samples are collected and they must be collected last (Puls and Barcelona, 1996). All sample containers should be filled with minimal turbulence by allowing the ground water to flow from the tubing gently down the inside of the container. When filling the VOC samples, a meniscus must be formed over the mouth of the vial to eliminate the formation of air bubbles and head space prior to capping. In the event that the ground water is turbid, (greater then 10 NTUs), a filtered metal (dissolved) sample also should be collected.

If filtered metal sample is to be collected, then an in-line filter is fitted at the end of the discharge tubing and the sample is collected after the filter. The in-line filter must be pre-rinsed following manufacturer's recommendations and if there are no recommendations for rinsing, a minimum of 0.5 to 1 liter of ground water from the monitoring well must pass through the filter prior to sampling.

16A. Non-dedicated system - Remove the pump from the monitoring well. Decontaminate the pump and dispose of the tubing if it is non-dedicated.

16B. Dedicated system - Disconnect the tubing that extends from the plate at the wellhead (or cap) and discard after use.

17. Non-dedicated system - Before locking the monitoring well, measure and record the well depth (to 0.1 feet).

Measure the total depth a second time to confirm initial measurement; measurement should agree within 0.01 feet or re-measure.

18. Non-dedicated and dedicated systems - Close and lock the well.

DECONTAMINATION PROCEDURES

Decontamination procedures for the water level meter and the water quality field parameter sensors.
The electronic water level indicator probe/steel tape and the water-quality field parameter sensors will be decontaminated by the following procedures:

1. The water level meter will be hand washed with phosphate-free detergent and a scrubber, then thoroughly rinsed with distilled water.

2. Water quality field parameter sensors and flow-through cell will be rinsed with distilled water between sampling locations. No other decontamination procedures are necessary or recommended for these probes since they are sensitive. After the sampling event, the flow cell and sensors must be cleaned and maintained per the manufacturer's requirements.

Decontamination Procedure for the Sampling Pump

Upon completion of the ground water sample collection the sampling pump must be properly decontaminated between monitoring wells. The pump and discharge line including support cable and electrical wires which were in contact with the ground water in the well casing must be decontaminated by the following procedure:

1. The outside of the pump, tubing, support cable and electrical wires must be pressure-sprayed with soapy water, tap water, and distilled water. Spray outside of tubing and pump until water is flowing off of tubing after each rinse. Use bristle brush to help remove visible dirt and contaminants.
2. Place the sampling pump in a bucket or in a short PVC casing (4-in. diameter) with one end capped. The pump placed in this device must be completely submerged in the water. A small amount of phosphate-free detergent must be added to the potable water (tap water).
3. Remove the pump from the bucket or 4-in. casing and scrub the outside of the pump housing and cable.
4. Place pump and discharge line back in the 4-in. casing or bucket, start pump and recirculate this soapy water for 2 minutes (wash).
5. Re-direct discharge line to a 55-gallon drum. Continue to add 5 gallons of potable water (tap water) or until soapy water is no longer visible.
6. Turn pump off and place pump into a second bucket or 4-in. casing that contains tap water. Continue to add 5 gallons of tap water (rinse).
7. Turn pump off and place pump into a third bucket or 4-in. casing which contains distilled/deionized water, continue to add 3 to 5 gallons of distilled/deionized water (final rinse).
8. If a hydrophobic contaminant is present (such as separate phase, high levels of PCBs, etc.), an additional decontamination step, or steps, may be added. For example, an organic solvent, such as reagent-grade isopropanol alcohol may be added as a first spraying/bucket prior to the soapy water rinse/bucket.

FIELD QUALITY CONTROL

Quality control (QC) samples must be collected to verify that sample collection and handling procedures were performed adequately and that they have not compromised the quality of the ground-water samples. The appropriate EPA program guidance must be consulted in preparing the field QC sample requirements for the site-specific Quality Assurance Project Plan (QAPP).

There are five primary areas of concern for quality assurance (QA) in the collection of representative ground-water samples:

1. Obtaining a ground-water sample that is representative of the aquifer or zone of interest in the aquifer. Verification is based on the field log documenting that the field water-quality parameters stabilized during the purging of the well, prior to sample collection.
2. Ensuring that the purging and sampling devices are made of materials, and utilized in a manner that will not interact with or alter the analyses.
3. Ensuring that results generated by these procedures are reproducible; therefore, the sampling scheme should incorporate co-located samples (duplicates).
4. Preventing cross-contamination. Sampling should proceed from least to most contaminated wells, if known. Field equipment blanks should be incorporated for all sampling and purging equipment, and decontamination of the equipment is therefore required.
5. Properly preserving, packaging, and shipping samples.

All field QC samples must be prepared the same as regular investigation samples with regard to sample volume, containers, and preservation. The chain-of-custody procedures for the QC samples will be identical to the field ground-water samples. The following are QC samples that must be collected during the sampling event:

	Sample Type	Frequency
●	Field duplicates	1 per 20 samples
●	Matrix spike	1 per 20 samples
●	Matrix spike duplicate	1 per 20 samples
●	Equipment blank	per Regional requirements or policy
●	Trip blank (VOCs)	1 per sample cooler
●	Temperature blank	1 per sample cooler

HEALTH AND SAFETY CONSIDERATIONS

Depending on the site-specific contaminants, various protective programs must be implemented prior to sampling the first well. The site Health and Safety Plan should be reviewed with specific emphasis placed on the protection program planned for the sampling tasks. Standard safe operating practices should be followed, such as minimizing contact with potential contaminants in both the liquid and vapor phase through the use of appropriate personal protective equipment.

Depending on the type of contaminants expected or determined in previous sampling efforts, the following safe work practices will be employed:

Particulate or metals contaminants

1. Avoid skin contact with, and incidental ingestion of, purge water.
2. Use protective gloves and splash protection.

Volatile organic contaminants

1. Avoid breathing constituents venting from well.
2. Pre-survey the well head space with an appropriate device as specified in the site Health and Safety Plan.
3. If monitoring results indicate elevated organic constituents, sampling activities may be conducted in level C protection. At a minimum, skin protection will be afforded by disposable protective clothing, such as Tyvek®.

General practices should include avoiding skin contact with water from preserved sample bottles, as this water will have pH less than 2 or greater than 10. Also, when filling pre-acidified VOA bottles, hydrochloric acid fumes may be released and should not be inhaled.

POST-SAMPLING ACTIVITIES

Several activities need to be completed and documented once ground-water sampling has been completed. These activities include, but are not limited to the following:

1. Ensuring that all field equipment has been decontaminated and returned to proper storage location. Once the individual field equipment has been decontaminated, tag it with date of cleaning, site name, and name of individual responsible.
2. Processing all sample paperwork, including copies provided to the Regional Laboratory, Sample Management Office, or other appropriate sample handling and tracking facility.
3. Compiling all field data for site records.
4. Verifying all analytical data processed by the analytical laboratory against field sheets to ensure all data has been returned to sampler.

REFERENCES

Gibs, J. and T.E. Imbrigiotta, 1990, Well-Purging Criteria for Sampling Purgeable Organic Compounds; Ground Water, Vol. 28, No. 1, pp 68-78.

Pohlmann, K.F. and A.J. Alduino, 1992, GROUND-WATER ISSUE PAPER: Potential Sources of Error in Ground-Water Sampling at Hazardous Waste Sites, US Environmental Protection Agency. EPA/540/S-92/019.

Puls, R.W. and M.J. Barcelona, 1996, GROUND-WATER ISSUE PAPER: Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedure, US Environmental Protection Agency. EPA/540/S-95/504, 12 pp.

Schuller, R.M., J.P. Gibb and R.A Griffin, 1981, Recommended Sampling Procedures for Monitoring Wells; Ground Water Monitoring Review, Spring 1981, pp. 42-46.

Parker, L.V. and T.A. Ranney, 1998, Sampling Trace-Level Organic Solutes with Polymeric Tubing: Part 2, Dynamic Studies; Ground Water Monitoring and Remediation, Vol. 18, No. 1, pp. 148-155.

U.S. Environmental Protection Agency, 1986, RCRA Ground-Water Monitoring Technical Enforcement Guidance Document; OSWER-9950.1, U.S. Government Printing Office, Washington, D.C., 208 pp., appendices.

U.S. Environmental Protection Agency, 1995, Ground Water Sampling - A Workshop Summary, Texas, November 30-December 2, 1993, EPA/600/R-94/205, 146 pp.

U.S. Environmental Protection Agency Region 1, 1996, Low Stress (low flow) Purging and Sampling Prodedure for the Collection of Ground water Samples From Monitoring Wells, SOP#: GW 0001, July 30, 1996.

U.S. Environmental Protection Agency Region 2, 1998, Ground Water Sampling Procedure Low Stress (Low Flow) Purging and Sampling, GW Sampling SOP Final, March 16, 1998.

Wilde, F.D., D.B. Radtke, J.Gibs and R.T. Iwatsubo, eds., 1998, National Field Manual for the Collection of Water-Quality Data; U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9, Handbooks for Water-Resources Investigations, variously paginated.

Wilkin, R.T., M.S. McNeil, C.J. Adair and J.T. Wilson, 2001, Field Measurement of Dissolved Oxygen: A Comparison of Methods, Ground Water Monitoring and Remediation, Vol. 21, No. 4, pp. 124-132.

SAMPLING CHECKLIST

Well Identification:________________________

Map of Site Included: Y or N
Wells Clearly Identified with Roads: Y or N
Well Construction Diagram Attached: Y or N

Well Construction:

Diameter of Borehole:________ Diameter of Casing:__________
Casing Material:____________ Screen Material:______________
Screen Length:_____________ Total Depth:______________

Approximate Depth to Water:_____________
Maximum Well Development Pumping Rate:_________________
Date of Last Well Development:_____________

Previous Sampling Information:

Was the Well Sampled Previously: Y or N
(If Sampled, Fill Out Table Below)

Table of Previous Sampling Information

Parameter	Previously Sampled	Number of Times Sampled	Maximum Concentration	Notes (include previous purge rates)

Ground Water Sampling Log

Site Name: **Well #:** **Date:**
Well Depth(Ft-BTOC[1]): **Screen Interval**(Ft):

Well Dia.: **Casing Material:** **Sampling Device:**

Pump placement(Ft from TOC[2]):

Measuring Point: **Water level (static)**(Ft):

Water level (pumping)(Ft): **Pump rate**(Liter/min):

Sampling Personnel:

Other info: (such as sample numbers, weather conditions and field notes)

Water Quality Indicator Parameters

Time	Pumping rates (L/Min)	Water level (ft)	DO (mg/L)	ORP (mv)	Turb. (NTU)	SEC[3] (S/cm)	pH	Temp. (C^0)	Volume pumped (L)

Type of Samples collected:

1 casing volume was:

Total volume purged prior to sample collection:

Stabilization Criteria

D.O.	+/- 0.3 mg/l
Turb.	+/- 10%
S.C.	+/- 3%
ORP	+/- 10 mV
pH	+/- 0.1 unit

[1]BTOC-Below Top of Casing
[2]TOC-Top of Casing
[3]Specific Electrical Conductance

ATTACHMENT 4
Example Standard Operating Procedure:

Standard Operating Procedure for the Standard/Well-Volume Method for Collecting a Ground-Water Sample

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Standard Operating Procedure for the Well-Volume Method for Collecting a Ground-Water Sample

INTRODUCTION

The collection of “representative” water samples from wells is neither straightforward nor easily accomplished. Ground-water sample collection can be a source of variability through differences in sampling personnel and their individual sampling procedures, the equipment used, and ambient temporal variability in subsurface and environmental conditions. Many site inspections and remedial investigations require the sampling at ground-water monitoring wells within a defined criterion of data confidence or data quality, which necessitates that the personnel collecting the samples are trained and aware of proper sample-collection procedures.

The objectives of the sampling procedures described in this document are to minimize changes in ground-water chemistry during sample collection and transport to the laboratory and to maximize the probability of obtaining a representative, reproducible ground-water sample. Sampling personnel may benefit from a working knowledge of the chemical processes that can influence the concentration of dissolved chemical species.

The well-volume method described in this standard operating procedure (SOP) provides a reproducible sampling technique with the goal that the samples obtained will represent water quality over an entire open interval of a short-screened (ten feet or less) well. This technique is appropriate for long-term and detection monitoring of formation water quality. The resulting sample generally represents a composite of the screened interval, and thus integrates small-scale vertical heterogeneities of ground-water chemistry. This sampling technique also is useful for screening purposes for detection monitoring of contaminants in the subsurface. However, the detection of a low concentration of contaminant in a thin contaminated zone or with long well screens may be difficult and should be determined using detailed vertical profiling techniques.

This method may not be applicable for all ground-water-sampling wells, such as wells with very low yields, fractured rock, and some wells with turbidity problems. As always, site-specific conditions and objectives should be considered prior to the selection of this method for sampling.

SCOPE AND APPLICATION

The objective of a good sampling program should be the collection of a representative sample of the current ground-water conditions over a known or specified volume of aquifer. To meet this objective, the sampling equipment, the sampling method, the monitoring well construction, monitoring well operation and maintenance, and sample-handling procedures should not alter the chemistry of the sample.

An example of how a site’s Data Quality Objectives (DQOs) for a characterization sampling effort might vary from those of a remediation monitoring sampling effort could be a difference of how much of the screened interval or aquifer should be sampled. A site characterization objective may be to collect a sample that represents a composite of the entire (or as close as is possible) screened interval of the monitoring well.

Additionally, the site characterization may require a large suite of contaminants to be sampled and analyzed, whereas, the remediation monitoring program may require fewer contaminants sampled and analyzed. These differences may dictate the type of sampling equipment used, the type of information collected, and the sampling protocol.

This sampling method described is for monitoring wells. However, this method should not be used for water-supply wells with a water-supply pump, with long-screened wells in complex hydrogeologic environments (such as fractured rock), or wells with separate phases of liquids (such as a Dense or Light Non-Aqueous Phase Liquids) present within the screened interval.

EQUIPMENT

- Depth-to-water measuring device - An electronic water-level indicator or steel tape and chalk, with marked intervals of 0.01 foot. Interface probe for measuring separate phase liquids, if needed. Pressure transducer and data logger optional for frequent depth-to-water measuring in same well.
- Steel tape and weight - Used for measuring total depth of well. Lead weights should not be used.
- Sampling pump - Submersible or bladder pumps with adjustable rate controls are preferred. Pumps

are to be constructed of inert materials, such as stainless steel and Teflon®. Pump types that are acceptable include gear and helical driven, centrifugal (low-flow type), and air-activated piston. Adjustable rate, peristaltic pumps can be used when the depth to water is 20 feet or less.

- Tubing - Inert tubing should be chosen based on the types and concentrations of contaminants present, or expected to be present in the monitoring well. Generally, Teflon®-based tubing is recommended when sampling for organic compounds. Polyethylene or Teflon® tubing can be used when sampling for inorganic constituents.
- Power source - If a combustion type (gasoline or diesel-driven) device is used, it must be located downwind of the point of sample collection. If possible, it should also be transported to the site and sampling location in a different vehicle from the sampling equipment.
- Flow-measurement equipment - Graduated cylinder or bucket and a stop watch, or a flow meter that can be disconnected prior to sampling.
- Multi-parameter meter with flow-through cell - This can be one instrument or multiple probes/instruments contained in a flow-through cell. The water-quality-indicator parameters that are measured in the field are pH, oxidation/reduction potential (ORP, redox, or Eh), dissolved oxygen (DO), turbidity, specific electrical conductance (SEC), and temperature. Calibration standards for all instruments should be NIST-traceable, within expiration dates of the solutions, and sufficient for daily calibration throughout the sampling collection.
- Decontamination supplies - A reliable and documented source of distilled water and any solvents (if used). Pressure sprayers, buckets or decontamination tubes for pumps, brushes and non-phosphate soap also will be needed.
- Sample bottles, sample preservation supplies and laboratory paperwork. Also, several coolers, and sample packing supplies (absorbing packing material, plastic baggies, etc.).
- Approved plans and background documents - Approved Field Sampling Plan, Quality Assurance Project Plan, well construction data, field and water-quality data from the previous sampling collection.
- Site Access/Permission documentation for site entry.
- Well keys and map showing locations of wells.
- Field notebook, field data sheets and calculator. A suggested field data sheet is provided at the end of this attachment.
- Filtration equipment - If needed, this equipment should be an in-line disposable filter used for the collection of samples for analysis of dissolved constituents.
- Polyethylene sheeting - Used for decontamination stations and during sampling to keep equipment clean.
- Site Health and Safety Plan and required equipment - The health and safety plan along with site sign-in sheet should be on site and be presented by the site health and safety officer. Personnel-protective and air-monitoring equipment specified in the Site Health and Safety Plan should be demonstrated, present and in good working order on site at all times.
- Tool box - All needed tools for all site equipment used.
- A 55-gallon drum or container to contain the purged water.

Construction materials of the sampling equipment (bladders, pump, bailers, tubing, etc.) should be limited to stainless steel, Teflon®, glass, and other inert materials when concentrations of the site contaminants are expected within the detection limit range. The sample tubing thickness and diameter should be maximized and the tubing length should be minimized so that the loss of contaminants absorbed to and through the tubing walls may be reduced and the rate of stabilization of ground-water parameters is maximized. The tendency of organics to sorb into and out of many materials makes the appropriate selection of sample tubing materials critical for these trace analyses (Pohlmann and Alduino, 1992; Parker and Ranney, 1998).

Generally, wells should be purged and sampled using the same positive-displacement pump and/or a low-flow submersible pump with variable controlled flow rates and constructed of chemically inert materials. If a pump cannot be used because the recovery rate of the well is so low (less than 100 to 200 ml/min) and the volume of the water to be removed is minimal (less than 5 feet of water in a small-diameter well), then a Teflon® bailer, with a double check valve and bottom-emptying device with a control-flow check valve may be used to obtain the samples. Otherwise, a bailer should not be used when sampling for volatile organics because of the potential bias introduced during sampling (Yeskis et al., 1988; Pohlmann et al., 1990; Tai et al., 1991). Bailers also should be avoided when sampling for metals because repeated bailer deployment has the potential to increase turbidity, which biases concentrations of inorganic constituents. Dedicated sampling pumps are recommended for metals sampling (Puls et al., 1992).

In addition, for wells with long riser pipes above the well screen, the purge volumes may be reduced by using packers above the pumps. The packer materials should be compatible with the parameters to be analyzed. These packers should be used only on wells screened in highly permeable materials, because of the lack of ability to monitor water levels in the packed interval. Otherwise, if pumping rates exceed the natural aquifer recovery rates into the packed zone, a vacuum or negative pressure zone may develop. This may result in a failure of the seal by the packer and/or a gaseous phase may develop, that may bias any sample taken.

PURGING AND SAMPLING PROCEDURE

WATER-LEVEL MEASUREMENTS

The field measurements should include total well depth and depth to water from a permanently marked reference point.

TOTAL WELL DEPTH

The depth of each well should be measured to the nearest one-tenth of a foot when using a steel tape with a weight attached and should be properly recorded. The steel tape should be decontaminated before use in another well according to the site specific protocols. A concern is that when the steel tape and weight hit the bottom of the well, sediment present on the bottom of a well is stirred up, thus increasing turbidity, which will affect the sampling results. In these cases, as much time as possible should be allowed prior to sampling, such as a minimum of 24 hours. If possible, total well depth measurements can be completed after sampling (Puls and Barcelona, 1996). The weight of electric tapes is generally too light to determine accurate total well depth. If the total well depth is greater than 200 feet, stretching of the tape must be taken into consideration.

DEPTH TO WATER

All water levels should be measured from the reference point by use of a weighted steel tape and chalk or an electronic water-level indicator (a detailed discussion of the pros and cons of the different water level devices is provided in Thornhill, 1989). The steel tape is a more accurate method to take water levels, and is recommended where shallow flow gradients (less than 0.05 feet/feet) or deep wells are encountered. However, in those cases where large flow gradients or large fluctuations in water levels are expected, a calibrated electric tape is acceptable. The water level is calculated using the well's surveyed reference point minus the measured depth-to-water and should be measured to the nearest one hundredth of a foot.

The depth-to-water measurement must be made in each well to be sampled prior to any other activities at the well (such as bailing, pumping, and hydraulic testing) to avoid bias to the measurement. All readings are to be recorded to the nearest one hundredth of a foot. When possible, depth-to-water and total well depth measurements should be completed at the beginning of a ground-water sampling program, which will allow any turbidity to settle and allow a more synoptic water-level evaluation. However, if outside influences (such as tidal cycles, nearby pumping effects, or major barometric changes) may result in significant water-level changes in the time between measurement and sampling, a water-level measurement should be completed immediately prior to sampling. In addition, the depth-to-water measurement during purging should be recorded, with the use of a pressure transducer and data logger sometimes more efficient (Barcelona et al., 1985, Wilde et al., 1998).

The time and date of the measurement, point of reference, measurement method, depth-to-water measurement, and any calculations should be properly recorded in field notebook or sampling sheet.

STATIC WATER VOLUME

From the information obtained for casing diameter, total well depth and depth-to-water measurements, the volume of water in the well is calculated. This value is one criteria that may be used to determine the volume of water to be purged from the well before the sample is collected.

The static water volume may be calculated using the following formula:

$$V = r^2h(0.163)$$

Where:

V = static volume of water in well (in gallons)
r = inner radius of well casing (in inches)
h = length of water column (in feet) which is equal to the total well depth minus depth to water.
0.163 = a constant conversion factor that compensates for the conversion of the casing radius from inches to feet for 2-inch diameter wells and the conversion of cubic feet to gallons, and pi (π). This factor would change for different diameter wells.

Static water volumes also may be obtained from various sources, such as Appendix 11.L in Driscoll (1986).

WELL PURGING

PURGE VOLUMES

In most cases, the standing water in the well casing can be of a different chemical composition than that contained in the aquifer to be sampled. Solutes may be adsorbed or desorbed from the casing material, oxidation may occur, and biological activity is possible. Therefore, the stagnant water within the well must be purged so that water that is representative of the aquifer may enter the well.

The removal of at least three well volumes is suggested (USEPA, 1986; Wilde et al., 1998). The amount of water removed may be determined by collecting it in a graduated pail of known volume to determine pumping rate and time of pumping. A flow meter may also be used, as well as capturing all purged water in a container of known volume.

The actual number of well volumes to be removed is based on the stabilization of water-quality-indicator parameters of pH, ORP, SEC, DO, and turbidity. The water initially pumped is commonly turbid. In order to keep the turbidity and other probes from being clogged with the sediment from the turbid water, the flow-through cell should be bypassed initially for the first well volume. These measurements should be taken and recorded every ½ well volume after the removal of 1 to 1 ½ well volume(s). Once three successive readings of the water-quality-indicator parameters provided in the table have stabilized, sampling may begin. The water-quality-indicator parameters that are recommended include pH and temperature, but these are generally insensitive to indicate completion of purging since they tend to stabilize rapidly (Puls and Barcelona, 1996). ORP may not always be an appropriate stabilization parameter, and will depend on site-specific conditions. However, readings should be recorded because of its value as a double check for oxidizing conditions, and for some fate and transport issues. When possible, especially when sampling for contaminants that may be biased by the presence of turbidity, the turbidity reading is desired to stabilize at a value below 10 Nephelometric Turbidity Units (NTUs). For final DO measurements, if the readings are less than 1 milligram per liter, they should be collected with the spectrophotometric method (Wilde et al., 1998, Wilkin et al., 2001), colorimetric or Winkler titration (Wilkin et al., 2001). All of these water-quality-indicator parameters should be evaluated against the specifications of the accuracy and resolution of the instruments used. No more than six well volumes should be purged, to minimize the over pumping effects described by Gibs and Imbrigiotta (1990).

Purging Methods

In a well that is not being pumped, there will be little or no vertical mixing in the water column between sampling events, and stratification may occur. The water in the screened section may mix with the ground water due to normal flow patterns, but the water above the screened section will remain isolated and become stagnant. Persons sampling should realize that stagnant water may contain foreign material inadvertently or deliberately introduced from the surface, resulting in unrepresentative water quality. To safeguard against collecting nonrepresentative stagnant water in a sample, the following guidelines and techniques should be adhered to during sample collection:

Table of Stabilization Criteria with References for Water-Quality-Indicator Parameters

Parameter	Stabilization Criteria	Reference
pH	+/- 0.1	Puls and Barcelona, 1996; Wilde et al., 1998
specific electrical conductance (SEC)	+/- 3%	Puls and Barcelona, 1996
oxidation-reduction potential (ORP)	+/- 10 millivolts	Puls and Barcelona, 1996
turbidity	+/- 10% (when turbidity is greater than 10 NTUs)	Puls and Barcelona, 1996; Wilde et al., 1998
dissolved oxygen (DO)	+/- 0.3 milligrams per liter	Wilde et al., 1998

1. As a general rule, monitoring wells should be pumped or bailed (although bailing is to be strongly avoided) prior to collecting a sample. Evacuation of a minimum of three volumes of water in the well casing is recommended for a representative sample. In a high-yielding ground-water formation where there is no stagnant water in the well above the screened section (commonly referred to as a water-table well), evacuation prior to sample withdrawal is not as critical but serves to field rinse and condition sampling equipment. The purge criteria has been described previously and will be again in the SAMPLING PROCEDURES section on the following page. The rate of purging should be at a rate and by a method that does not cause aeration of the water column and should not exceed the rate at which well development was completed.

2. For wells that can be pumped or bailed to dryness with the sampling equipment being used, the well should be evacuated to just above the well screen interval and allowed to recover prior to sample withdrawal. (Note: It is important not to completely dewater the zone being sampled, as this may allow air into that zone which could result in negative bias in organic and metal constituents.) If the recovery rate is fairly rapid and time allows, evacuation of more than one volume of water is preferred.

3. A non-representative sample also can result from excessive prepumping of the monitoring well. Stratification of the contaminant concentrations in the ground-water formation may occur or heavier-than-water compounds may sink to the lower portions of the aquifer. Excessive pumping can decrease or increase the contaminant concentrations from what is representative of the sampling point of interest, as well as increase turbidity and create large quantities of waste water.

The method used to purge a well depends on the inner diameter, depth-to-water level, volume of water in the well, recovery rate of the aquifer, and accessibility of the well to be sampled. The types of equipment available for well evacuation include hand-operated or motor-driven suction pumps, peristaltic pumps, submersible pumps, and bailers made of various materials, such as stainless steel and Teflon®. Whenever possible, the same device used for purging the well should be left in the well and used for sampling, generally in a continual manner from purging directly to sampling without altering position of the sampling device or turning off the device.

When purging/sampling equipment must be reused in other wells, it should be decontaminated consistent with the decontamination procedures outlined in this document. Purged water should be collected and screened with air-monitoring equipment as outlined in the site health and safety plan, as well as water-quality field instruments. If these parameters and/or the facility background data suggest that the water is hazardous, it should be contained and disposed of properly as determined on a site-specific basis.

During purging, water-level measurements should be recorded regularly for shallow wells, typically at 15- to 30-second intervals. These data may be useful in computing aquifer transmissivity and other hydraulic characteristics, and for adjusting purging rates. In addition, these data will assure that the water level doesn't fall below the pump intake level

SAMPLING PROCEDURES

Ground-water sample collection should take place immediately following well purging. Preferably, the same device should be used for sample collection as was used for well purging, minimize further disturbance of the water column, and reduce volatilization and turbidity. In addition, this will save time and avoid possible contamination from the introduction of additional equipment into the well, as well as using equipment materials already equilibrated to the ground water. Sampling should occur in a progression from the least to most contaminated well, if known, when the same sampling device is used.

The sampling procedure is as follows:

1) Remove locking well cap. Note location, time of day, and date in field notebook or on an appropriate log form.
2) Note wind direction. Stand upwind from the well to avoid contact with gases/vapors emanating from the well.
3) Remove well casing cap.
4) If required by site-specific conditions, monitor headspace of well with appropriate air-monitoring equipment to determine presence of volatile organic compounds or other compounds of concern and record in field logbook.
5) If not already completed, measure the water level from the reference measuring point on the well casing or protective outer casing (if inner casing not installed or inaccessible) and record it in the field notebook. Alternatively, if no reference point exists, note that the water level measurement is from the top of the outer protective casing, top of inside riser pipe, ground surface, or some other position on the well head. Have a permanent reference point established as soon as possible after sampling. Measure at least twice to confirm measurement; the measurement should agree within 0.01 feet or re-measure. Decontaminate the water-level-measuring device.
6) If not already completed, measure the total depth of the well (at least twice to confirm measurement; the measurement should agree within 0.01 feet or re-measure) and record it in the field notebook or on log form. Decontaminate the device used to measure total depth. If the total well depth has been measured recently (in the past year), then measure it at the conclusion of sampling.
7) Calculate the volume of water in the well and the volume to be purged using the formula previously provided.
8) Lay plastic sheeting around the well to minimize the likelihood of contamination of equipment from soil adjacent to the well.
9) Rinse the outside of sampling pump with distilled water and then, while lowering the pump, dry it with disposable paper towels.
10) Lower the pump (or bailer) and tubing down the well. The sampling equipment should never be dropped into the well because this will cause degassing of the water upon impact. This may also increase turbidity, which may bias the metals analysis. The lowering of the equipment should be slow and smooth!
11) The pump should be lowered to a point just below the water level. If the water level is above the screened interval, the pump should be above the screened interval for the reasons provided in the purging section.
12) Turn the pump on. The submersible pumps should be operated in a continuous, low-flow manner so that they do not produce pulsating flows, which cause aeration in the discharge tubing, aeration upon discharge, or resuspension of sediments at the bottom of the well. The sampling pump flow rates should be lower than or the same as the purging rates. The purging and sampling rates should not be any greater than well development rates.
13) Water levels should be monitored during pumping to ensure that air does not enter the pump and to help determine an appropriate purging rate.
14) After approximately one to two well volumes are removed, a flow-through cell will be hooked up to the discharge tubing of the pump. If the

well discharge water is not expected to be highly turbid, contain separate liquid phases, or minimal bacterial activitiy that may coat or clog the electrodes within the flow-through cell, then the cell can be immediately hooked up to the discharge tubing. This cell will allow measurements of water-quality-indicator parameters without allowing contact with the atmosphere prior to recording the readings for temperature, pH, ORP, SEC, DO and turbidity.

15) Measurements for temperature, pH, ORP, SEC, DO, and turbidity will be made at each one-half well volume removed. Purging may cease when measurements for all five parameters have stabilized (provided in the earlier table) for three consecutive readings.

16) If the water level is lowered to the pump level before three volumes have been removed, the water level will be allowed to recover for 15 minutes, and then pumping can begin at a lower flow rate. If the pump again lowers the water level to below the pump intake, the pump will be turned off and the water level allowed to recover for a longer period of time. This will continue until a minimum of two well volumes are removed prior to taking the ground-water sample.

17) If the water-quality-indicator parameters have stabilized, sample the well. Samples will be collected by lowering the flow rate to a rate that minimizes aeration of the sample while filling the bottles (approximately 300 ml/min). Then a final set of water-quality-indicator parameters is recorded. The pump discharge line is rapidly disconnected from the flow-through cell to allow filling of bottles from the pump discharge line. The bottles should be filled in the order of volatile organic compounds bottles first, followed by semi-volatile organic compound's/pesticides, inorganics, and other unfiltered samples. Once the last set of samples is taken, if filtering is necessary, an in-line disposable filter (with appropriately chosen filter size) will be added to the discharge hose of the pump. Then the filtered samples will be taken. If a bailer is used for obtaining the samples, filtering occurs at the sampling location immediately after the sample is obtained from the bailer by using a suction filter. The first one-half to one liter of sample taken through the filter will not be collected, in order to assure the filter media is acclimated to the sample. If filtered samples are collected, WITHOUT EXCEPTION, filtering should be performed in the field as soon as possible after collection, and not later in a laboratory.

18) All appropriate samples that are to be cooled, are put into a cooler with ice immediately. All of the samples should not be exposed to sunlight after collection. Keep the samples from freezing in the winter when outside temperatures are below freezing. The samples, especially organics, cyanide, nutrients, and other analytes with short holding times, are recommended to be shipped or delivered to the laboratory daily. Ensure that the appropriate samples that are to be cooled remain at 4^{o}C, but do not allow any of the samples to freeze.

19) If a pump cannot be used because the recovery rate is slow and the volume of the water to be removed is minimal (less than 5 feet of water), then a Teflon® bailer, with a double check valve and bottom-emptying device with a control-flow check valve will be used to obtain the samples. The polypropylene rope used with the bailer will be disposed of following the completion of sampling at each well.

20) The pump is removed from the well and decontaminated for the next sampling location.

Additional precautions to ensure accurate and representative sample collection are as follows:

- Check valves on bailers, if bailers are used, should be designed and inspected to ensure that fouling problems do not reduce delivery capabilities or result in aeration of the sample.
- The water should be transferred to a sample container in a way that will minimize agitation and aeration.
- If the sample bottle contains no preservatives, the bottle should be rinsed with sample water, which is discarded before sampling. Bottles for sample analyses that require preservation should be prepared before they are taken to the well. Care should be taken to avoid overfilling bottles so that the preservative is not lost. The pH should be checked and more preservatives added to inor-

ganic sample bottles, if needed. VOA bottles that do not meet the ph requirements need to be discarded and new sample bottles with more preservative added should be prepared immediately.

- Clean sampling equipment should not be placed directly on the ground or other contaminated surfaces either prior to sampling or during storage and transport.

Special Consideration for Volatile Organic Compound Sampling

The proper collection of a sample for dissolved volatile organics requires minimal disturbance of the sample to limit volatilization and therefore a loss of volatiles from the samples. Preferred retrieval systems for the collection of un-biased volatile organic samples include positive displacement pumps, low-flow centrifugal pumps, and some in-situ sampling devices. Field conditions and other constraints will limit the choice of appropriate systems. The principal objective is to provide a valid sample for analysis, one that has been subjected to the least amount of turbulence possible.

1) Fill each vial to just overflowing. Do not rinse the vial, nor excessively overflow it, as this will effect the pH by diluting the acid preservative previously placed in the bottle. Another option is to add the acid at the well, after the sample has been collected. There should be a convex meniscus on the top of the vial.
2) Do not over tighten and break the cap.
3) Invert the vial and tap gently. Observe the vial closely. If an air bubble appears, discard the sample and collect another. It is imperative that no entrapped air remains in the sample vial. Bottles with bubbles should be discarded, unless a new sample cannot be collected, and then the presence of the bubble should be noted in the field notes or field data sheet. If an open sample bottle is dropped, the bottle should be discarded.
4) Orient the VOC vial in the cooler so that it is lying on its side, not straight up.
5) The holding time for VOCs is 14 days. It is recommended that samples be shipped or delivered to the laboratory daily. Ensure that the samples remain at 4°C, but do not allow the samples to freeze.

Field Filtration of Turbid Samples

The USEPA recognizes that in some hydrogeologic environments, even with proper well design, installation, and development, in combination with the low-flow rate purging and sampling techniques, sample turbidity cannot be reduced to ambient levels. The well construction, development, and sampling information should be reviewed by the Regional geologists or hydrologists to see if the source of the turbidity problems can be resolved or if alternative sampling methods should be employed. If the water sample is excessively turbid, the collection of both filtered and unfiltered samples, in combination with turbidity, Total Suspended Solids (TSS), Total Dissolved Solids (TDS), pumping rate, and drawdown data is recommended. The filter size used to determine TSS and TDS should be the same as used in the field filtration. An in-line filter should be used to minimize contact with air to avoid precipitation of metals. The typical filter media size used is 0.45 µm because this is commonly accepted as the demarcation between dissolved and non-dissolved species. Other filter sizes may be appropriate, but their use should be determined based on site-specific criteria (examples include grain-size distribution, ground-water flow velocities, mineralogy) and project DQOs. Filter sizes up to 10.0 µm may be warranted because larger size filters may allow particulates that are mobile in ground water to pass through (Puls and Powell, 1992). The changing of filter media size may limit the comparability of the data obtained with other data sets and may affect their use in some geochemical models. Filter media size used on previous data sets from a site, region, or aquifer and the DQOs should be taken into consideration. The filter media used during the ground-water sampling program should be collected in a suitable container and archived because potential analysis of the media may be helpful for the determination of particulate size, mineralogy, etc.

The first 500 to 1000 milliliters of sample taken through the filter, depending on sample turbidity, will not be collected for a sample, in order to ensure that the filter media has equilibrated to the sample. Manufacturers' recommendations also should be consulted. Because bailers have been shown to increase turbidity while purging and sampling, they should be avoided when sampling for trace element, metal, PCB, and pesticide constituents. If portable sampling pumps are used, the pumps should be gently lowered to the sampling depth desired, carefully avoiding being lowered to the bottom of the well. The pumps, once placed in the well, should not be moved to allow any particles mobilized by pump placement to settle. Dedicated sampling equipment installed in the well prior to the commencement of the sampling activities is one of the recommended methods to reduce turbidity artifacts (Puls and Powell, 1992; Kearl et al., 1992; Puls et al., 1992; Puls and Barcelona, 1996).

DECONTAMINATION PROCEDURES

Once removed from the well, the purging and sampling pumps should be decontaminated by scrubbing with a brush and a non-phosphate soapy-water wash, rinsed with water, and rinsed with distilled water to help ensure that there is no cross-contamination between wells. The step-by-step procedure is:

1) Pull pump out of previously sampled well (or out of vehicle) and use three pressure sprayers filled with soapy water, tap water, and distilled water. Spray outside of tubing and pump until water is flowing off of tubing after each rinse. Use bristle brush to help remove visible dirt, contaminants, etc.
2) Have three long PVC tubes with caps or buckets filled with soapy water, tap water and distilled water. Run pump in each until approximately 2 to 3 gallons of each decon solution is pumped through tubing. Pump at low rate to increase contact time between the decon solutions and the tubing.
3) Try to pump decon solutions out of tubing prior to next well. If this cannot be done, compressed air may be used to purge lines. Another option is to install a check valve in the pump line (usually just above the pump head) so that the decon solutions do not run back down the well as the pump is lowered down the next well.
4) Prior to lowering the pump down the next well, spray the outside of the pump and tubing with distilled water. Use disposable paper towels to dry the pump and tubing.
5) If a hydrophobic contaminant is present (such as separate phase, high levels of PCBs, etc.), an additional decon step, or steps, may be added. For example, an organic solvent such as reagent-grade isopropanol alcohol may be added as a first rinse prior to the soapy water rinse.

If the well has been sampled with a bailer that is not disposable, the bailer should be cleaned by washing with soapy water, rinsing with tap water, and finally rinsing with distilled water. Bailers are most easily cleaned using a long-handled bottle brush.

It is especially important to clean thoroughly the portion of the equipment that will be in contact with sample water. In addition, a clean plastic sheet should be placed adjacent to or around the well to prevent surface soils from coming in contact with the purging equipment. The effects of cross-contamination also can be minimized by sampling the least contaminated well first and progressing to the more contaminated ones. The bailer cable/rope (if a bailer is used) and plastic sheet should be properly discarded, as provided in the site health and safety plan, and new materials provided for the next well.

FIELD QUALITY CONTROL

The quality assurance (QA) targets for precision and accuracy of sampling programs are based on accuracy and precision guidelines established by the USEPA. When setting targets, keep in mind that all measurements must be made so that the results are representative of the sample water and site-specific conditions. Various types of blanks are used to check the cleanliness of the field-handling methods. These are known as field blanks, and include field equipment blanks and transport blanks. Other QA samples include spike samples and duplicates.

There are five primary areas of concern for QA in the collection of representative ground-water samples:

1. Obtaining a sample that is representative of water in the aquifer or targeted zone of the aquifer. Verify log documentation that the well was purged of the required volume or that the temperature, pH, ORP, SEC, DO and turbidity stabilized before samples were extracted.

2. Ensuring that the purging and sampling devices are made of materials and utilized in a manner that will not interact with or alter the analyses.
3. Generating results that are reproducible. Therefore, the sampling scheme should incorporate co-located samples (duplicates).
4. Preventing cross-contamination. Sampling should proceed from least to most contaminated wells, if known. Field equipment blanks should be incorporated for all sampling and purging equipment; decontamination of the equipment is therefore required.
5. Ensuring that samples are properly preserved, packaged, and shipped.

FIELD EQUIPMENT BLANKS

To ensure QA and quality control, a field equipment blank must be included in each sampling run, or for every twenty samples taken with the sampling device. Equiptment blanks allow for a cross check and, in some cases, quantitative correction for imprecision that could arise due to handling, preservation, or improper cleaning procedures.

Equipment blanks should be taken for each sample bottle type that is filled. Distilled water is run through the sampling equipment and placed in a sample bottle (the blank), and the contents are analyzed in the lab like any other sample. Following the collection of each set of twenty samples, a field equipment blank will be obtained. It is generally desirable to collect this field equipment blank after sampling a relatively highly contaminated well. These blanks may be obtained through the following procedure:

a) Following the sampling event, decontaminate all sampling equipment according to the site decontamination procedures and before collecting the blank.
b) VOA field blanks should be collected first, prior to water collected for other TAL/TCL analyses. A field blank must be taken for all analyses.
c) Be sure that there is enough distilled water in the pump so that the field equipment blank can be collected for each analysis.
d) The water used for the field equipment blank should be from a reliable source, documented in the field notebooks, and analyzed as a separate water-quality sample.

TRIP BLANKS

A trip blank should be included in each sample shipment and, at a minimum, one per 20 samples. Bottles, identical to those used in the field, are filled with reagent-grade water. The source of the reagent-grade water should be documented in the field notebooks, including lot number and manufacture. This sample is labeled and stored as though it is a sample. The sample is shipped back to the laboratory with the other samples and analysis is carried out for all the same constituents.

DUPLICATE SAMPLES

Duplicate samples are collected by taking separate samples as close to each other in time and space as practical, and should be taken for every 20 samples collected. Duplicate samples are used to develop criteria for acceptable variations in the physical and chemical composition of samples that could result from the sampling procedure. Duplicate results are utilized by the QA officer and the project manager to give an indication of the precision of the sampling and analytical methods.

HEALTH AND SAFETY CONSIDERATIONS

Depending on the site-specific contaminants, various protective programs must be implemented prior to sampling the first well. The site health and safety plan should be reviewed with specific emphasis placed on the protection program planned for the sampling tasks. Standard safe operating practices should be followed, such as minimizing contact with potential contaminants in both the liquid and vapor phases through the use of appropriate personal protective equipment.

Depending on the type of contaminant expected or determined in previous sampling efforts, the following safe work practices will be employed:

Particulate or metals contaminants

1. Avoid skin contact with, and accidental ingestion of, purge water.
2. Wear protective gloves and splash protection.

Volatile organic contaminants

1. Avoid breathing constituents venting from well.
2. Pre-survey the well head space with an appropriate device as specified in the Site Health and Safety Plan.
3. If air monitoring results indicate elevated organic constituents, sampling activities may be conducted in Level C protection. At a minimum, skin protection will be afforded by disposable protective clothing, such as Tyvek®.

General practices should include avoiding skin contact with water from preserved sample bottles, as this water will have pH less than 2 or greater than 10. Also, when filling, pre-preserved VOA bottles, hydrochloric acid fumes may be released and should not be inhaled.

POST-SAMPLING ACTIVITIES

Several activities need to be completed and documented once ground-water sampling has been completed. These activities include, but are not limited to:

- Ensuring that all field equipment has been decontaminated and returned to proper storage location. Once the individual field equipment has been decontaminated, tag it with date of cleaning, site name, and name of individual responsible.
- Processing all sample paperwork, including copies provided to Central Regional Laboratory, Sample Management Office, or other appropriate sample handling and tracking facility.
- Compiling all field data for site records.
- Verifying all analytical data processed by the analytical laboratory against field sheets to ensure all data has been returned to sampler.

REFERENCES

Barcelona, M.J., J.P. Gibb, J.A. Hellfrich and E.E. Garske, 1985, Practical Guide for Ground-Water Sampling; U.S. Environmental Protection Agency, EPA/600/2-85/104, 169 pp.

Driscoll, F.G., 1986, Groundwater and Wells, 2nd Ed.; Johnson Division, St. Paul, Minnesota, 1089 pp.

Gibs, J. and T.E. Imbrigiotta, 1990, Well-Purging Criteria for Sampling Purgeable Organic Compounds; Ground Water, Vol. 28, No. 1, pp 68-78.

Herzog, B.L., S.J. Chou, J.R. Valkenburg and R.A. Griffin, 1988, Changes in Volatile Organic Chemical Concentrations After Purging Slowly Recovering Wells; Ground Water Monitoring Review, Vol. 8, No. 4, pp. 93-99.

Kearl, P.M., N.E. Korte, and T.A. Cronk, 1992, Suggested Modifications to Ground Water Sampling Procedures Based on Observations from the Colloid Borescope; Ground Water Monitoring Review, Vol. 12, No. 2, pp. 155-161.

Keely, J.F. and K. Boateng, 1987, Monitoring Well Installation, Purging, and Sampling Techniques - Part 1: Conceptualizations; Ground Water, Vol. 25, No. 4 pp. 427-439.

McAlary, T.A. and J.F. Barker, 1987, Volatilization Losses of Organics During Ground Water Sampling from Low Permeability Materials; Ground Water Monitoring Review, Vol. 7, No. 4, pp. 63-68.

Nielson, D.M., 1991, Practical Handbook of Ground-Water Monitoring; Lewis Publishers, 717 pp.

Parker, L.V. and T.A. Ranney, 1998, Sampling Trace-Level Organic Solutes with Polymeric Tubing: Part 2, Dynamic Studies; Ground Water Monitoring and Remediation, Vol. 18, No. 1, pp. 148-155.

Pohlmann, K.F., R.P. Blegen, and J.W. Hess, 1990, Field Comparison of Ground-Water Sampling Devices for Hazardous Waste Sites: An Evaluation using Volatile Organic Compounds; EPA/600/4-90/028, 102 pp.

Pohlmann, K.F. and A.J. Alduino, 1992, GROUND-WATER ISSUE PAPER: Potential Sources of Error in Ground-Water Sampling at Hazardous Waste Sites; US Environmental Protection Agency. EPA/540/S-92/019.

Puls, R.W. and R.M. Powell, 1992, Acquisition of Representative Ground Water Quality Samples for Metals; Ground Water Monitoring Review, Vol. 12, No. 3, pp. 167-176.

Puls, R.W., D.A. Clark, B. Bledsoe, R.M. Powell and C.J. Paul, 1992, Metals in Ground Water: Sampling Artifacts and Reproducibility; Hazardous Waste and Hazardous Materials, Vol. 9, No. 2, pp. 149-162.

Puls, R.W. and M.J. Barcelona, 1996, GROUND-WATER ISSUE PAPER: Low-Flow (Minimal Drawdown) Ground-Water Sampling Procedures; U.S. Environmental Protection Agency, EPA/540/S-95/504, 12 pp.

Tai, D.Y., K.S. Turner, and L.A. Garcia, 1991, The Use of a Standpipe to Evaluate Ground Water Samples; Ground Water Monitoring Review, Vol. 11, No. 1, pp. 125-132.

Thornhill, J.T., 1989, SUPERFUND GROUND WATER ISSUE: Accuracy of Depth to Water Measurements; US Environmental Protection Agency. EPA/540/4-89/002, 3 pp.

U.S. Environmental Protection Agency, 1986, RCRA Ground-Water Monitoring Technical Enforcement Guidance Document; OSWER-9950.1, U.S. Government Printing Office, Washington, D.C., 208 pp., appendices.

U.S. Environmental Protection Agency, 1995, Ground Water Sampling-A Workshop Summary, Dallas, Texas, November 30-December 2, 1993, EPA/600/R-94/025, 146 pp.

Wilde, F.D., D.B. Radtke, J.Gibs and R.T. Iwatsubo, eds., 1998, National Field Manual for the Collection of Water-Quality Data; U.S. Geological Survey Techniques of Water-Resources Investigations, Book 9, Handbooks for Water-Resources Investigations, variously paginated.

Wilkin, R.T., M.S. McNeil, C.J. Adair and J.T. Wilson, 2001, Field Measurement of Dissolved Oxygen: A Comparison of Methods, Ground Water Monitoring and Remediation, Vol. 21, No. 4, pp. 124-132.

Yeskis, D., K. Chiu, S. Meyers, J. Weiss and T. Bloom, 1988, A Field Study of Various Sampling Devices and Their Effects on Volatile Organic Contaminants; Proceedings of the Second National Outdoor Action Conference on Aquifer Restoration, Ground Water Monitoring and Geophysical Methods, National Water Well Association, May, 1988.

GROUND-WATER SAMPLING RECORD

Well ID:____________

Station #:____________

Facility Name: Date:____/____/____

Well Depth:__________ Depth to Water:__________ Well Diameter:__________

Casing Material.:__________ Volume Of Water per Well Volume:____________

Sampling Crew:______________,________________,________________,________________

Type of Pump:________ __________ Tubing Material:______________ Pump set at ______________ ft.

Weather Conditions:__________________________ NOTES:________ ________________

GROUND-WATER SAMPLING PARAMETERS

Time	Water Level	Volume Pumped	Pumping Rate	DO (mg/l)	Temp. (^{0}C)	SEC (µS/cm)	pH	ORP (mV)	Turbidity (NTU)

Other Parameters: ______________

Sampled at:____________ Parameters taken with :______________________________

Sample delivered to ______________________ by ____________________ at__________.

Sample CRL #:__________ OTR #:__________ ITR #:__________ SAS #:____________

Parameters Collected	Number of Bottles	Bottle Lot Number