Ground-Water Sampling Guidelines for Superfund and RCRA Project Managers

GROUND WATER FORUM ISSUE PAPER

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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.

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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.)

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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).

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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.

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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 physio-chemical 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

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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

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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

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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.

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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

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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).

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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

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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.

[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.

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

Stabilization Criteria

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

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

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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, semi-volatile 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.

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- 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

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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

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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

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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

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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.

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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)

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 :

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

Stabilization Criteria

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

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

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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

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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.

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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:

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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

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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

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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°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-

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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

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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.

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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.

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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.

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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