Low-Flow/Low-Volume Purging and Sampling of Ground-Water Monitoring Wells - Performance and Application Criteria

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Abstract: Sampling ground water has traditionally involved purging a monitoring well to remove stagnant water in the well casing prior to sampling. The traditional approach of purging three to five volumes of the well can produce large volumes of purge water and can affect sample quality and greatly increase sample turbidity that could result in "false-positive" or biased analytical results

Low-flow/low-volume sampling is a methodology that can be used to overcome many of the limitations created by traditional well volume purging. Low-flow/low-volume sampling can control sample turbidity and minimize sample chemistry alteration by pumping at very low flow rates from the well screen zone, avoiding disturbance to the water column in the well and minimizing stress on the surrounding formation. By pumping water only from the screen zone and not significantly drawing water from the casing above the screen (if present), the volume of water purged to achieve stable water chemistry can be reduced significantly. Samples obtained in this manner will better reflect the ground-water chemistry at ambient flow conditions and the true mobile load of contaminants if present.

Keywords: Ground water sampling, monitoring, contamination monitoring.

I. Introduction

Sampling ground water has traditionally involved purging a monitoring well to remove stagnant water in the well casing prior to sampling. The traditional approach of purging three to five volumes of the well can produce large volumes of purge water, and users often resort to high pumping rates to purge efficiently. Where purge water must be collected or treated, handling and containerizing purge water is difficult and expensive, and treatment costs can add greatly to sampling budgets.

Where wells are set in low hydraulic conductivity formations, they may not yield water sufficiently to allow continuous purging of multiple well volumes. These low-yield wells have traditionally been "evacuated" (dewatered) and allowed to recover prior to sampling. Due to the use of high pumping rates, wells that could readily be pumped continuously at sustained low rates (< 1 liter/minute) without evacuation are often improperly considered to be "low yield" and are evacuated. The well evacuation approach poses several problems:

- Purging below top of screen can cause water entering the well to "cascade" inside the well screen as the well recovers, resulting in a change in dissolved gasses and redox state and ultimately affecting the concentration of the analytes of interest through the oxidation of dissolved metals and possible loss of VOCs;

- Dewatering the screen drains water from the sand pack surrounding the screen, resulting in air being trapped in the pore spaces with lingering effects on dissolved gas levels and redox state;

- Where the well screen is submerged, drawdown below the top of the screen could induce movement of vadose zone gases into the well, resulting in false-positive or biased analytical results for VOCs.

- Stress on the formation and stirring up of any settled solids in the bottom of the well can result in increased sample turbidity.

- The time required for sufficient recovery of the well may be excessive, affecting sample chemistry through prolonged exposure to the atmosphere. In some cases, the well may not recover sufficiently to produce the sample volume required within a reasonable time period;

These traditional purging methods can affect sample quality and greatly increase sample turbidity that could result in "false-positive" or biased analytical results. Overcoming excessive turbidity by using sample filtration to remove suspended solids can affect sample chemistry, resulting in a sample that doesn't accurately reflect the ground water and adding to the time and cost of sampling and analysis.

Low-flow/low-volume sampling is a methodology that can be used to overcome many of the limitations created by traditional well volume purging. Low-flow/low-volume sampling can control sample turbidity and minimize sample chemistry alteration by pumping at very low flow rates from the well screen zone, avoiding disturbance to the water column in the well and minimizing stress on the surrounding formation. By pumping water only from the screen zone and not significantly drawing water from the casing above the screen (if present), the volume of water purged to achieve stable water chemistry can be reduced significantly. Samples obtained in this manner will better reflect the ground-water chemistry at ambient flow conditions and the true mobile load of contaminants if present.

II. Applicability

Low-flow/low-volume sampling is appropriate for collection of ground-water samples for all ground-water contaminants and any naturally occurring analytes, including metals and other inorganics, pesticides, PCBs, volatile and semi-volatile organic compounds (VOCs and SVOCs), other organic compounds, radiochemical and microbiological constituents. This method is not applicable to the collection of light or dense non-aqueous phase liquids (LNAPLs or DNAPLs). This method can be applied to wells that meet the following criteria:

- The well can be pumped at a constant low flow rate of 0.1 to 1.0 liter/minute without continuous drawdown of the water level in the well. (See Section V on Passive Sampling for low-yield wells that produce less than 0.1 L/min.)

- The maximum well screen or open borehole intake length should be 20 feet when sampling from a single point within the intake. Where the intake length exceeds 20 feet, a sampling system should be used that allows for capture of samples from multiple points within the intake, either separately or as a composite sample, unless a target zone within the screen can be identified (see Pump Placement, below).

III. Application Requirements

A. Pump Placement

Where a well is screened or open across a single geologic unit and the screen or open borehole is not more than twenty feet long, the pump intake should be positioned in the mid-point of the screen/intake zone, provided that this zone is fully submerged. It is assumed under these conditions that water will be drawn from the entire intake area, even under low-flow pumping rates. Where the analytes of interest are known to concentrate near the top or the bottom of the screen zone, it maybe desirable to locate the pump intake to target this zone. Where the water column within the well is very short (<10 feet), it may be necessary to locate the pump intake near the bottom of the water column to ensure adequate pump performance. To avoid mobilization and entrainment of settled solids in the well, the pump intake should be at least one foot from the bottom of the well.

Where the screen/intake zone is longer than 20 feet and a target zone cannot be identified based on either geology or target analytes, a sampling device with a multi-level inlet can be used. The inlets can be positioned to target individual zones or can be spaced evenly along the inlet to combine water from the zones for a composite sample of the entire well intake.

As with many other purging methods, detailed knowledge of lithology, hydrogeologic properties and well constructions details along with the specific goals and objectives of the monitoring program can assist in proper sampling point location and improve the potential of obtaining representative samples of the zone of interest.

B. Flow Rate

One objective of low-flow/low-volume sampling is to minimize any mobilization of solids that are not naturally mobile under ambient flow conditions. The flow rate used during purging must be low enough to avoid increasing turbidity. Measurement of turbidity during purging is used to determine proper flow rates without overpumping (see Indicator Parameter Measurement, below).

The flow rate used should be determined for each well, based on the hydraulic performance of the well. The flow must be adjusted to obtain stabilization of the pumping water level in the well as quickly as possible (see Water Level Measurement and Drawdown, below). ***In any case, the maximum flow rate used should not greatly exceed 1 liter/minute.*** If possible, the optimum flow rate for each well should be established during well development or redevelopment, or in advance of the actual sampling event. Once established, this rate should be reproduced with each subsequent sampling event.

C. Water Level Measurement and Drawdown

Measurement of the water level in the well during purging is important when establishing the optimum flow rate for purging. As stated in US EPA's guidance document (April 1996), "The goal is minimal drawdown during purging.

This goal may be difficult to achieve under some circumstances due to geologic heterogeneities within the screened interval, and *may require adjustment based on site-specific conditions and personal experience* (emphasis added)." Since drawdown in the well creates some mixing of water above the screen zone with water in the screen, minimizing drawdown will reduce the volume of water that must be purged from the well to achieve removal of this mixed water and stabilization of indicator parameters. Therefore, keeping drawdown to the minimum that is practically achievable will reduce the time required for proper purging.

The goal is to achieve a ***stabilized pumping water level*** as quickly as possible with minimal drawdown to avoid stressing the formation and mobilizing solids and to obtain stabilized indicator parameters in the shortest time possible. The drawdown level may be as little as a few inches in wells that are good producers or as much as several feet in lower yield wells. It is far more important to achieve a stabilized water level in a well during purging than to achieve a particular drawdown value, as each well will respond differently to pumping. Once the pumping water level has stabilized, the well screen zone will be hydraulically isolated from any remaining stagnant water above, and stabilization of the purging indicator parameters can be expected shortly thereafter.

For wells that are constructed with fully submerged screens, it is preferable to maintain the water level at some point above the well screen during pumping. However, drawdown below the top of the screen is acceptable, provided that a constant pumping rate can be maintained during purging and samples are taken prior to complete recovery of the well. Where drawdown below the top of the screen is unavoidable, there is potential that vadose zone gases could enter the well and affect the samples. Care should be taken to avoid sampling the uppermost water in the well to minimize the potential for gas effects.

D. Measurement of Indicator Parameters and Turbidity

Continuous monitoring of water quality indicator parameters is used to determine when purging is competed and sampling should begin. Stabilized values, based on selected criteria, indicate that conditions are suitable for sampling. Commonly used indicator parameters are temperature, pH, conductivity and dissolved oxygen. Research and personal experience have shown dissolved oxygen and conductivity (specific conductance) to be the most reliable indicators, with dissolved oxygen to be the most conservative parameter.

An in-line flow cell system is recommended for measuring indicator parameters. Indicator parameters should be considered stable when three consecutive readings fall within the predetermined ranges for the parameters of interest. The frequency of readings should be based on the time required to purge one volume of the flow cell. For example, a 500-ml flow cell purged at a rate of 250 ml/minute will be purged in two minutes, so readings should be ***at least*** two minutes apart. An example of indicator parameters and the ranges for stabilized values is shown below:

Temperature:	± 0.5° C
pH:	± 0.2 units
Conductance:	± 5.0 % of reading
Dissolved oxygen:	± 10 % of reading or 0.2 mg/L, whichever is greater

It is important to identify the range, resolution and accuracy of the instruments used to determine if the selected stabilization criteria can be measured. If the instruments available cannot accurately measure the stabilization criteria above, consult with the regulatory program manager to determine if different criteria values would be appropriate for your sampling program.

Sources of turbidity in ground-water wells can include naturally occurring solids from the formation, artifactual solids from well construction (drilling fluid, sand pack, grout), and even bacteria that often flourish with the introduction of a well into a previously undisturbed formation. Turbidity in a well is most affected by disturbance to the water column and by stress induced on the surrounding formation, such as from bailing or excessive pumping. Naturally occurring turbidity levels in ground water can exceed 10 NTU (Puls & Barcelona, 1996).

While turbidity is not a direct measurement of water ***chemistry*** and is not used as an indicator parameter when purging a monitoring well prior to sampling, it is useful as a measure of the pumping stress on the formation and to establish the proper pumping rate to minimize sample turbidity. The level of turbidity in a ground-water sample could affect the ability to determine accurately the dissolved concentration of organic or inorganic analytes. The actual turbidity value that might affect analyte concentration will vary based on the nature of the solids present and the characteristics of the analytes of interest.

To avoid artifacts in sample analysis, turbidity should be as low as possible when samples are taken. Turbidity should be measured at least three times, once when purging is initiated, again after the water level in the well stabilizes, and again when the water chemistry indicator parameters being measured are stable. Turbidity should also be measured again any time the pumping rate is increased or the water level in the well drops noticeably. If the initial turbidity reading is high (>50 NTU) and the second reading is not significantly lower, the pump rate should be reduced. The turbidity value measured prior to sampling should be recorded. If this value exceeds 25 NTU, procedures should be reviewed and the source of the elevated turbidity determined if possible. High turbidity readings could be the result of excessive pumping rates, sampling equipment insertion/removal, a need for well maintenance or possible well design, installation or damage problems.

IV. Equipment

A. Purging and Sampling Systems

Because the methodology requires that disturbance to the water column in the well is minimized, only pumping devices should be used for low-flow/low-volume purging and sampling. Grab samplers, thief samplers, syringe samplers and bailers are not acceptable. Preferred devices are positive-displacement down-well pumps that can be placed with the pump intake within the well screen/intake and that have adjustable flow rate control. Peristaltic and other suction lift pumps should be avoided because they may cause degassing, redox (ORP) and pH changes, and loss of VOCs, especially at lifts greater than 10-15 feet. Inertial lift pumps should not be used, since their operation requires continuous movement through the water column in the well, which can cause mixing and elevated turbidity levels and adversely affect sampling results.

Small diameter tubing is preferred, in order to minimize the purge volume of the sampling system and ensure adequate sample volume will be available; 1/4-inch (0.250") and 3/8-inch (0.375) diameters are preferred. Teflon® or Teflon-lined polyethylene tubing is required for sampling any organics; polyethylene may be used where target analytes excludes organics.

B. Operating Mode - Dedicated and Portable Systems

There are two approaches to using ground-water sampling equipment, portable and dedicated. Portable systems are installed just prior to use in a well, then thoroughly cleaned (decontaminated) prior to use in another well. Dedicated systems are installed in each well, and remain in place in the well between sampling events.

Studies have shown that the installation of the sampling pump just prior to use causes mixing of the stagnant water in the casing with the water in the screen/intake zone. Insertion also increases suspended solids in the water column due to disturbance of settled and adhered solids in the casing and agitation of water in the sand pack. Therefore, low-flow/low-volume sampling techniques are more accurate when using dedicated systems. Dedicated systems result in lower initial turbidity values and lower purge volumes to achieve stabilized indicator parameter readings.

If portable systems are used, they should be placed carefully into the well and lowered into the screen zone as slowly as possible. Studies on the use of dedicated and portable pumps for low-flow sampling show that portable pumps can be used, but stabilization of the indicator parameters will take longer due to the mixing from insertion of the pump, and initial turbidity levels may be higher (Puls and Paul, 1995).

C. Water-Level Measurement Equipment

Water levels can be measured during pumping with continuous water-level measurement devices (e.g., down-hole pressure transducers or bubbler lines) or electronic water-level tapes. Specialized water level tapes are available that function as drawdown meters, indicating when drawdown has reached the selected level. Any device used should be capable of measuring to 0.01-foot accuracy.

D. Indicator Parameter and Turbidity Measurement Equipment

Measurement of indicator parameters (temperature, pH, specific conductance, and dissolved oxygen) should be performed using an in-line flow cell system attached directly to the pump discharge tubing. It is desirable to have an instrument that can record or log readings during pumping. The stated accuracy of the instrument must equal or exceed the ranges shown above for parameter stabilization. Standards for calibration of the system are required, and manufacturer's instructions for calibration should be followed.

For turbidity measurement, a field nephelometer should be used. A flow cell is not required for turbidity measurements, but may be desirable if automatic data collection is preferred.

V. "Passive" Sampling (Minimal Purge Sampling)

Where wells are set in very low hydraulic conductivity formations, it may not be possible to achieve a stabilized water level in a well even when pumping at very low flow rates (less than 100 ml/minute). The traditional approach to sampling these very low yield wells has been to evacuate the wells and sample upon recovery. As noted above, the well evacuation approach can greatly affect sample chemistry and turbidity, and should therefore be avoided.

For wells that cannot achieve a stabilized water level even at very low pumping rates, an alternative to the traditional evacuation approach is to use "passive" or minimal purge sampling techniques to avoid the pitfalls of well evacuation and obtain a better and probably more representative sample. Sampling the water present in the screen zone provides the greatest chance of obtaining samples with minimal alteration of the chemistry. Although the low movement rate of the ground water in the screen provides only a limited exchange, avoiding the alteration caused by the factors mentioned above is really the best alternative.

The passive/minimal purge approach requires the removal of the smallest possible purge volume prior to sampling, generally limited to the volume of the sampling system. The sampling system volume is minimized by using very small diameter tubing and the smallest possible pump chamber volume. Plastic tubing should have sufficient wall thickness to minimize the potential for oxygen transfer through the tubing when pumping at very low flow rates. After purging 1-3 volumes of the sampling system, samples are taken from the subsequent water pumped. Since passive sampling requires the minimum possible disturbance to the water column and surrounding formation, dedicated sampling systems are required for this approach.

The pumping rates used for passive/minimal purge sampling are much lower than for low-flow/low-volume purging, generally 100 ml/minute or less. Drawdown is expected, since it cannot be avoided; however, it is still advisable to pump at the lowest possible rate to limit drawdown to the minimum possible. As with low-flow/low-volume techniques, the water level in the well should not be lowered below the top of the screen if possible.

Monitoring indicator parameters for stability is not part of this approach, since the intention is not to purge until stabilization of these measurements. However, pumping through a flow cell is still the best way to get field measurements prior to sampling. Where the total volume of water in the well is very small, field measurements can be accomplished with a very small volume flow cell (< 50 ml), or grab sampling and measurement can be used. It may be necessary to work with the analytical laboratory to reduce the sample volumes to the minimum possible to reduce the total volume of water removed. This is also useful from a practical standpoint, since the time required to fill larger sample containers may be lengthy at the very low flow rates used.

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