

Groundwater Quality Monitoring

Overview

Groundwater sampling may be required for a variety of reasons, such as examining potable or industrial water supplies, checking for and/or tracking contaminant plume movement in the vicinity of a waste disposal or spill site, compliance monitoring, or examining a site where historical information is minimal or non-existent but where it is thought that ground water contamination may have occurred.

Groundwater quality monitoring can be performed at any stage of mining for different objectives. Prior to initiation of mining, groundwater quality can be sampled and/or monitored to gather background data of natural site conditions. Groundwater quality can also be monitored during mining for determining mining impact on the surrounding environment and/or for compliance monitoring. Groundwater quality must also be examined with scrutiny following mine closure for meeting compliance criteria as well as for assessing the performance of closure measures.

Groundwater quality sampling and groundwater quality monitoring are two terms that are often used interchangeably and it is perhaps important to point out they in fact relate to different activities. Groundwater “sampling” refers to the action of extracting/collecting, containerizing, and preserving a volume of groundwater either from a monitoring well, during drilling, from a spring or any other potential source of groundwater, in most cases for the purpose of sending the sample to an analytical laboratory. In comparison, groundwater quality “monitoring” refers to the determination of physico-chemical parameters inherent to a body of groundwater using measuring probes without necessarily collecting a sample for analysis.

There exist a vast array of groundwater sampling techniques varying in degrees of performance and complexity and relative unit cost. While groundwater quality sampling is typically performed by pumping water from monitoring wells, sampling can also be performed at any time during drilling or can also be performed in-situ by direct-push methods. Groundwater can also be sampled in underground mines where groundwater

flows through drain holes. Sampling of monitoring well is likely the most controlled/regulated sampling method and several standard sampling protocols were developed by North American regulatory agencies over the years.

This paper presents a summary of the following groundwater quality sampling methods of current use in North America:

- Direct Sampling;
- Monitoring Well Sampling;
- Multi-Level Piezometer Sampling (with inflatable packers);
- Drainhole Sampling (in underground mines);
- Direct-Push Sampling (*in-situ* method);
- Spring Sampling (artesian conditions).

The selection of any given groundwater sampling method will depend on factors such as particular project objective, relative cost (\$), drilling method, site location, etc...

Groundwater sampling methods

Direct Sampling

Direct sampling pertains to the “on-going” collection of groundwater sample and determination of water quality parameters (such as pH, EC/TDS, temperature...) as drilling proceeds and groundwater is purged/flushed out of a borehole. The first sample at a given depth should be considered only indicative of real groundwater conditions and any test data shall be seen as preliminary.

Depending on the drilling method used groundwater can be brought to surface by several methods namely during yield test, bailing, surging, etc... For any given depth, the longer the water “retrieval” period the more representative the water sample of “true” groundwater conditions, i.e. mixing and drilling-induced influences are diminished.

Monitoring Well Sampling

Groundwater samples are usually obtained from either temporarily or permanently installed ground water monitoring wells. They can also be obtained, however, anywhere groundwater is present, such as in a pit or a dug or drilled hole, or as discussed below in underground mine workings. Wells should be sampled immediately upon completion of purging operations. If the well is evacuated (purged dry) during the purging procedures, the sample should be collected as soon as a sufficient volume of water has recovered in the well.

Groundwater sampling procedures can be sub-divided into two areas, purging and sampling, each having its own objectives. Purging is the process of removing stagnant water from a monitoring well prior to sampling, causing its replacement by groundwater from the adjacent formation, which is representative of actual aquifer conditions. The purge of a monitoring well must be performed at all times prior to water quality sampling. Monitoring well purging is usually accomplished by bailing or pumping. However, it should be stated that the use of bailers for purging and sampling is discouraged because the correct technique is highly operator-dependent (EPA, 1996).

A well will presumably be adequately flushed for collection of a representative sample when indicator parameters such as pH, temperature, electrical conductivity (EC) and turbidity are observed to vary less than the criteria presented in Table 1. A detailed discussion on purging and groundwater sampling procedure in monitoring wells is presented in a Standard Operating Procedure (SOP) produced by Robertson GeoConsultants Inc. (RGC, 2002). These parameters, along with the volume of water removed should be closely monitored and recorded by the field investigator. Purging of three to six well volumes may be necessary to meet the indicator parameter criterion. If the parameters have not stabilized within six well volumes, it is at the discretion of the project geo-scientist whether or not to collect a sample or to continue purging (U.S. EPA, 1996). In any case, the conditions of sampling should be noted in the field log.

However, in wells with very low recoveries this amount may not be practical. In some situations, a well may be pumped/bailed dry even with slow purge rates. In these situations,

this generally constitutes an adequate purge and the well can be sampled following sufficient recovery of the water level in the well (i.e. enough water to fill all sample containers). It is not necessary that the well be flushed three times before it is sampled (EPA, 1996). Field parameters should then be recorded as being the valid measurements for the sampling event.

Groundwater sampling activities can only proceed once a monitoring well has been purged and water quality parameters have stabilized. The following section presents a summary of sampling techniques commonly used for groundwater monitoring wells. Methods are listed in order from the least preferred to the most preferred sampling method.

Table 1. Water-quality-indicator parameter stabilization criteria and calibration guidelines.
(adapted from USGS, 2002)

Parameter	Stabilization Criteria (variability should be within the value shown)	Calibration Guidelines
Temperature (thermistor may be part of other instrument)	± 0.2 °C ¹	Calibrate annually, check calibration quarterly.
Specific conductance for =100 $\mu\text{S/cm}$ for > 100 $\mu\text{S/cm}$	± 5 percent ¹ ± 3 percent ^{1,2}	Calibrate each morning. Check calibration at each sample site; recalibrate if not within 3-5% of standard value.
pH	± 0.1 unit ^{1,2}	Calibrate each morning. Check calibration at each sample site; recalibrate if not within 0.05 pH units.
Turbidity*	± 10 percent ^{1,2}	Calibrate with a primary standard on a quarterly basis. Check calibration against secondary standards at the beginning of each trip.
Oxidation-reduction potential	± 10 mV ²	Check against ZoBell's solution at the start and end of each trip (more often if necessary).

\pm , plus or minus value shown; °C, degrees Celsius; =, less than or equal to value shown; $\mu\text{S/cm}$, microsiemens per centimeter at 25°C; >, greater than value shown; unit, standard pH unit; mg/L, milligram per liter; mv, millivolts; NTU, nephelometric turbidity unit]; n/a, not applicable.

¹ USGS recommendation (Wilde, F.D., and Radtke, D.B, 1998)

² EPA recommendation (Puls and Barcelona, 1996)

* Turbidity criteria should not be too stringent to avoid excessive purge times (Puls and Barcelona, 1996).

Turbidity criteria may need to be modified if difficulty in stabilization is encountered.

- **Air-Lifting**

Air-lifting is one of several methods typically used for well development, which is performed in order to (i) remove the residual materials remaining in the well casing and screen area after installation has been completed and (ii) re-establish the natural hydraulic flow conditions of the formation, which may have been disrupted by well construction and/or drilling activities.

In this method, compressed air is injected (forced) down the bore (well casing) using a hose to agitate (lift) the water column and ultimately remove fines out of the formation and filter pack and into the well bore. The sediment-laden water is then allowed to discharge some distance (say 1-2m) above the top of the well screen. To develop a well by this method, there must be at least 20% submergence of the air discharge line (Nielsen, 1991). For example, a well completed at 50m bgs will require at least 10m of free water above the screen for successful development by air-lifting.

Because of its rather “aggressive” nature, air-lifting is not particularly well suited for groundwater sampling primarily because compressed air is injected into the formation and hence can potentially affect water quality by influencing such parameters as pH and redox potential.

Also, care should be taken not to force compressed air into the formation through the well screen because this could push fines into the formation and “blind” the well screen area. It is imperative, that the compressed air discharge line of the air compressor includes a functioning oil/air separator filter (RGC, 2002). This filter on the discharge line of the air compressor should be checked after development of each well for proper functioning to avoid oil contamination in the well.

Caution must be taken when using high rate or large volume air compressors during air-lifting (either for well development or sampling) because excessive high air pressures can damage the well screen and filter pack.

- **Bailing**

Bailing monitoring wells is probably one of the oldest methods for developing, purging and sampling in monitoring wells. Bailers are durable and simple to operate and they are also very inexpensive, so much so that many are considered disposable. A brief introduction to bailers and their application in groundwater sampling is provided by EnviroEquip (2001).

<http://www.enviroequip.com/quipnotes/Bailers.htm>

Bailers typically consist of standard-cleaned closed-top polyethylene or Teflon® tubes equipped with a ball valve. Bailers are connected to a clean (new) nylon/PVC rope through a leader and are lowered into the top of the water column, allowed to fill, and subsequently removed.

Hand bailing may be utilized in any case, but in general is more efficient in shallow monitoring wells with a low recharge rate. The bailer should also be washed and rinsed. A new length of either nylon or PVC cord should be used for each well and for each evacuation event (RGC, 2002). It is critical that bailers be slowly and gently immersed into the top of the water column. It should be stated that the use of bailers for purging and sampling is discouraged because the correct technique is highly operator-dependent (EPA, 1996).

The main advantages of bailing lie in its simplicity, affordability and portability. However, bailing is inefficient and its main disadvantage perhaps is the method is prone to contamination. On the other hand sampling pumps may not be suitable for purging or sampling some wells in some situations. These situations could arise as a result of budget limitations, site logistics or even monitoring well characteristics. Pros and cons of using bailers for groundwater sampling are discussed by EnviroEquip (2001).

Purging with bailers

Monitoring wells can be purged with the use of a bailer. This is a simple process for lowering the bailer into the well, allowing it to fill completely and then removing it from the well and emptying it and then repeating the process. Typically, purging a well will require removing a prerequisite number of well volumes. Since the bailer is a known volume, it is a simple matter to calculate the number of times the well must be bailed in

order to complete the purging process. The purging process is very tedious, however this can be minimized by using a heavy bailer that will sink faster and also by using nylon bailer cord which also sinks faster than polypropylene cord.

Sampling with bailers

Bailers can be used for collecting samples of groundwater for almost any type of analysis provided that the proper care is taken. In order to ensure sample quality, it is important to minimize the amount a sample is agitated when it is removed from the well. In order to achieve this the bailer should be lowered into the well carefully so that it does not splash when it contacts the water in the well. When the bailer has been lowered to the depth where the sample is to be collected, it should be removed from the well with a constant steady motion. Pulling the bailer up in a series of steps will tend to cycle water through the bailer because of the elastic nature of the bailer cord and the momentum of the water in the bailer. It is important to remove the bailer in a steady motion in order to avoid this (see

Waterra

recommendations,

<http://www.waterra.com/pages/application%20pages/bailing.html>

). Most operators use an alternating hand over hand motion to lift the bailer from the well, this also helps prevent the cord from becoming tangled.

Once the bailer has been removed from the well, the sample can be removed from the bailer by one of two methods. Some people will decant the sample from the top of the bailer by carefully tipping it into their sample container. The drawback with this method is that it exposes the sample to the atmosphere, which may be undesirable for some types of samples. The weight distribution of the bailer also changes rapidly as the water flows out the top of the bailer and may result in spillage.

Bottom emptying may be preferable for most types of samples. Bottom emptying usually involves inserting a device into the bottom of the bailer after it has been removed from the well. This device gently lifts the ball from the bailers valve seat allowing a stream of water to flow out the bottom of the bailer through the device. This stream is usually regulated such that it is suitable for filling small sample containers such as VOC sample containers. This stream of water is ideal for this type of sampling as the sample's contact with the atmosphere is minimized.

Filtered samples for metals analysis can also be collected from many types of bailers by simply attaching an Inline Disposable field Filter to the outlet of the bottom emptying device and allowing the sample to flow by gravity through the filter (see Waterra website).

Today, many people prefer to use disposable bailers because of their low cost and the advantages they offer like the elimination of cross contamination. Disposable bailers can also be dedicated to monitoring wells, however this is generally not recommended as there is still a risk that they may become contaminated. Disposable bailers are individually packaged and each contains its own bottom emptying device .

- **Waterra Inertial Pump**

Narrow diameter monitoring wells (2 inch) have been used in Canada for many years now. The Waterra Inertial Pump was developed for use in such narrow diameter monitoring wells. The Waterra Initial Pump (WIP)

([http://www.waterra.com/pages/techpapers/TechA\(Groundwater%20Monitoring\)/techA1.html](http://www.waterra.com/pages/techpapers/TechA(Groundwater%20Monitoring)/techA1.html)) consists only of a foot valve and a length of plastic tubing that when oscillated up and down in the well produces a flow of water. In general, the Waterra system is simple and offers adequate performance for shallow monitoring well application at a relatively affordable price. Dedicated sampling systems are regarded by many ground water professionals to provide better quality and more representative samples at a dramatically reduced cost. Waterra pumps cost little more than bailers to dedicate, yet equal or exceed far more costly pumps in performance.

Well development is an important part of monitoring well procedures and is usually required in order to acquire a quality sample and adequately determine formation parameters such as permeability. It has been stated in some instances that the Waterra Inertial Pump action on the monitoring well may increase turbidity in cases where a monitoring well requires development.

The WIP can be used successfully for well development with capacity for 2 inch (5cm) and certain 4 inch (10cm) wells due to the combination of simultaneous pumping and gentle well surging. This draws fines into the well and effectively removes them. The

capacity of the Waterra pump can be enhanced with the addition of the well development Surge Block Ring, which is a plastic ring that increases the outside diameter of the footvalve. This reduces the annular gap between the valve and the well screen. With less annular gap the surging effect of the system is significantly enhanced. Waterra (waterra website) provides useful recommendation regarding the design of a well development/sampling system.

Using the WIP is relatively simple. A valve is securely threaded onto the tubing. The tubing is then inserted into the well, valve first. If a surge block is to be used it should be installed on the valve by pressing it on about halfway up the valve. The tubing is fed down to the depth of the screened interval and then cut about six feet (2 m) above the top of the well. Pumping is initiated by pumping by hand at the rate corresponding to the desired flow. Pumping can also be mechanized by a drive system, which has the advantage to that the field person is available to do other tasks whilst purging. The Inertial Pump is operated by oscillating the tubing and foot valve assembly up and down in the monitoring well.

As described above, the Waterra system is mostly suited for well development. However, groundwater sampling can also be performed with the Waterra Initial Pump immediately after well purging is completed and sampling equipment has been flushed properly. The field person responsible for sampling should be careful to adopt a low-flow of pumping in order to minimize aeration of the groundwater as it is extracted from the monitoring well. Additional information on operating principles can be found on the Waterra website.

- **Well Pumping**

The device with the lowest pump or water removal rate and the least tendency to stress the well during purging should be selected for use. For example, if a bailer and a peristaltic pump both work in a given situation, the pump should be selected because it will greatly minimize the turbidity, providing a higher quality sample (EPA, 1996). If a Fultz® pump or a Grundfos Redi-Flo2® pump could both be used, the Redi-Flo2® may be given preference because the speed can be controlled to provide a lower pump rate, thereby minimizing turbidity.

If a submersible pump is used for purging and/or sampling, the pump itself is lowered into the water column. The pump must previously be cleaned (RGC, 2002). Sampling pumps (e.g. the Grundfos Redi-Flo2® pump) can be used for both the sampling and purging of the well. Wells may be purged with any submersible pump using a uniform rate of discharge. Any pump that causes excessive water aeration or agitation should not be used. The intake/discharge lines should be composed of polyethylene tubing lined with Teflon®. Only positive pressure pumps are used for sampling purposes. The selection of an evacuation (purging) method mostly depends on the expected recharge of the well. If the recharge is anticipated to be rapid, a hand pump can be used.

The pump/hose assembly should be lowered into the top of the standing water column and not deep in the column. This is done so that the purging will “pull” water from the formation into the screen area of the well and up through the casing so that the entire static volume can be removed. If the pump is placed deep into the water column, the water above the pump may not be removed, and the subsequent samples, particularly if collected with a bailer, may not be representative of the groundwater (EPA, 1996).

At the beginning of pumping, the pump rate should be adjusted according to the estimated yield of the well. It is recommended that no more than 1.0-1.5m of hose be lowered into the water column. If the recovery rate of the well is faster than the pump rate and no observable draw down occurs, then the pump rate should be raised until the intake is within 0.5m of the top of the water column for the duration of purging. If the pump rate exceeds the recovery rate of the well, the pump will have to be lowered, as needed, to accommodate the draw down. After the pump is removed from the well, all wetted portions of the hose and the pump should be cleaned.

Robertson GeoConsultants Inc. provides detailed Standard Operating Procedures (SOP) for groundwater well sampling using a submersible pump.

- **Low Flow Pumping**

The low flow/low volume purging and sampling is a procedure used to minimize purge water volumes. This method is nowadays the favored method for sampling groundwater monitoring wells for several reasons mentioned in the following paragraphs. A review of

low-flow purging/sampling techniques is provided by Ritchey (2002), as first published in ASTM Standardization News, April 2002 Issue.

<http://www.enviroequip.com/pdf/Low%20Flow%20Sampling-J.%20Ritchey.pdf>

In this method, the pump intake is placed within the screened interval at the zone of sampling, preferably the zone with the highest flow rate. Low flow rate purging/sampling is conducted after hydraulic conditions with the well have re-stabilized, usually within 24-48 hours following drilling and well installation. Flow rates should not exceed the recharge rate of the aquifer. This is monitored by measuring the top of the water column with a water level recorder while pumping. These techniques, however, are only acceptable under certain hydraulic conditions and are not considered standard procedures.

The United States Environmental Protection Agency provides a reference paper that is widely respected as a resource for persons who need or wish to use Low-Flow purging and sampling as a method of sampling the groundwater at their site.

<http://www.enviroequip.com/quipnotes/lowflowepa.htm>

The USGS (2002) provides the following discussion on low-flow sampling procedures:

Low-flow purging and sampling techniques are increasingly being used as an alternative to traditional approaches that require purging 3 to 5 casing volumes to determine the appropriate time for sample collection. When properly applied, this sampling methodology will not artificially bias suspended particle concentrations (Puls and Barcelona, 1996). By using low pumping rates and limiting water-level drawdown, only particles being advected by ground water are sampled, thereby minimizing the potential for introduction of artificial suspended solids into the sample (Kearl and others, 1994; Sevee and others, 2000). Small, steady-state drawdown is a “necessary and sufficient condition” for low-flow techniques. Excessive drawdown and resultant increased velocity and turbulence affect whether the low-flow technique will be practical (Sevee and others, 2000).

According to the USGS National Field Manual for the Collection of Water-Quality Data:

“Low-flow (micropurge) purging procedures are designed to minimize the volume of purge water and are applicable to some studies and sites at which the pump intake is to be located within the screened/open interval and a low rate of flow can be maintained without compromising sample integrity for the target analytes (usually unfiltered trace elements) (Kearl and others, 1992; Puls and Powell, 1992; Puls and Barcelona, 1996). The low flow method requires either

a permanently installed (dedicated) pump capable of low flow rates, or a waiting period of 24 hours after installing and before starting a portable pump” (Wilde and others, 1999).

The following paper briefly summarizes the benefits of low-flow sampling versus traditional methods such as bailers.

<http://www.enviroequip.com/pdf/QEDWhatWhyHow.PDF>

An example of standard operating procedures (SOP) for low-flow sampling of groundwater monitoring wells is provided by the USGS (2002) following extensive work on watersheds in New Mexico, USA. Puls and Barcelona (1996) also provide a low-flow groundwater sampling procedures, which were prepared for the USEPA.

Drain Holes Sampling

In underground mines, groundwater can be sampled where drain holes are present. Drainholes are points in the rock mass where groundwater flow exits into a mine working. They are more likely to be found in areas where the bedrock is fractured and hence provide a flow path for groundwater. The geology of the structures and discontinuities should be known in order to define the geometry of the rock mass and hopefully identify the source of groundwater.

Alternatively, groundwater can be collected in underground mines from interception system or drainage pipes. Regardless of where it is collected, the groundwater sampled in underground workings can be very useful for load balance calculations since it can often be combined with flow estimates.

(Section to be completed with CW's ideas---> I'm running short of ideas here)

Multi-Level Piezometer Sampling

Defining the extent of groundwater contaminant plume in geologic materials requires three-dimensional analysis of sampling points. Westbay ([link to .pdf paper](#)) has developed a sampling system which addresses this need. Their system embodies a

modular casing system which allows a large number of monitoring zones to be established in a single borehole. Valved port couplings provide access to individual zones from a common casing. Individual screened intervals are isolated by packers. There are several key benefits associated with this system, namely significantly reduced installation costs, and virtual elimination of purgewater.

Certain multiport samplers making use of packers can also be combined with a single, direct-push-installed well to collect groundwater from a range of depths.

The USEPA developed a standard operating procedure (SOP) to describe the process for sampling of multi-completion monitoring wells using the Westbay MP System® for the Los Alamos National Laboratory (LANL), Environmental Restoration Project (ER).

http://erproject.lanl.gov/Common/Procedures/SOPs/ER-SOP-06.32_R1A.pdf

Other multi-level groundwater sampling systems are commercially available. For example, the FLUTe (http://flut.com/app_1.htm) system is mostly used for deeper applications in stable holes (e.g., core holes in fractured rock or multi screened casing in unstable media).

Direct-Push Method

Direct push (DP) is an alternative method to conventional drilling techniques for sampling soil and groundwater, and installing monitoring wells in unconsolidated materials such as clay, silt, sand, and gravel. Many sites where groundwater is contaminated are located over aquifers of unconsolidated sands and gravels. DP methods do not use rotary augering to advance tools or install wells as conventional drilling methods do. DP methods use percussion hammers and static vehicle weight combined with hydraulic cylinders to advance tools to depth. The DP methods do not generate a large volume of potentially contaminated drill cuttings as conventional drilling methods do. The U.S. Environmental Protection Agency (USEPA) provides a detailed discussion of the direct-push sampling method and its application to environmental engineering.

http://fate.clu-in.org/direct_push/dpgroundwater_main.asp#plume

A large-scale U.S. Navy sponsored performance comparison was conducted at a major MTBE cleanup site in Port Hueneme, California. The study found almost no difference between samples collected from small diameter direct push wells and those collected from conventional drilled wells. However this comparative study demonstrated that DP methods permit faster and cheaper monitoring well installation, generates no cuttings and generates 3-4 times less liquid than rotary drilling methods.

<http://www.enviroequip.com/quipnotes/directpushVconvent.htm>

The ASTM 2002 Standard Guide (www.astm.org) for Direct Push Soil Sampling (D 6282) and Standard Guide for Direct Push Groundwater Sampling (D 6001) have been published and are now available from ASTM for determining the most appropriate sampling methods for a site investigation project.

Links to on-line resources and vendors of DP technology are provided below.

<http://www.geoprobe.com>

<http://www.ams-samplers.com>

BAT

The BAT system (named after the inventor, Bengt Arne Torstensson, 1984)--->make clickable to the .pdf file... is an in situ testing/sampling method for the characterization of soils and groundwater, which allows discrete-depth water sampling. The *BAT* is hydraulically pushed with the same equipment used for cone penetration testing (CPT). Once enough sampling is carried out at a specific depth, the *BAT* probe is then pushed to the next depth and the procedure repeated. There is no limit to the number of samples that can be taken at one location.

Campanella (1999) provides a discussion on a modified version of the original *BAT* system, which allows the direct measurement of permeability in sands and gives more accurate and feasible sampling in higher TDS environments as experienced, for example, during water sampling in metallic mine tailings.

The US-EPA and other high conformance requirement groups have adopted *BAT* technology as appropriate and preferred for many environmental characterization applications. The attraction of no drill cuttings and the repeatability of the data are cited

as the key reasons for this reference. *BAT* technology has been scrutinized by many investigators and has met with widespread acceptance (e.g., Zemo et al., 1992).

Spring Sampling

In addition to the above-mentioned methods, groundwater samples can also be collected at ground surface where springs are present, i.e. in areas under artesian conditions. Artesian water is ground water under sufficient pressure to rise above the point at which it is encountered in wells, or more simply water rises to ground surface to form what is commonly called a spring. A well that flows at the land surface is known as a flowing artesian well.

As defined by the Kansas Geological Survey (KGS, 2002), artesian conditions exist where a water-bearing bed is overlain by an impermeable or relatively impermeable bed that dips from its outcrop to the discharge area. Water enters the water-bearing bed at the outcrop and percolates slowly downward to be held in the water-bearing bed by the overlying confining bed. Down the dip from the outcrop area, the water exerts considerable pressure against the confining bed. When a well is drilled through the confining bed into the water-bearing bed the pressure is released and the water rises in the well. If the water is under sufficient pressure, and if the altitude of the land surface is lower than the altitude of the outcrop of the water-bearing bed, the water may rise high enough to flow at the surface. In places where there are lenses or beds of relatively impermeable clay or silt at the level of the water table, the water encountered below such lenses or beds will rise to the level of the surrounding water table, but such water is under normal pressure and is not artesian.

See link below for figure:

http://www.kgs.ukans.edu/General/Geology/Finney/06_gw3.html

Groundwater can be readily sampled where artesian conditions prevail by collecting water as close to the source of the spring as possible.

Standard Operating Procedures (SOP)

Links to practical SOP's for selected groundwater sampling methods are provided below.

- Groundwater Monitoring Wells Sampling using a submersible pump, by RGC (2002)
- Groundwater Monitoring Wells Sampling using low-flow techniques, by USGS (2002)
- Multi-Level Groundwater Sampling with the MP System, by Environmental Restoration Project (2002)

References (to be completed)

ASTM, 2002. Direct-Push Groundwater Sampling. Annual Book of ASTM Standards 2002, Volume 4.09 – Soil and Rock (II): D5780-D6575, Method D6001.

Banar, Alethea (2002): Multi-level Groundwater Sampling of Monitoring Wells - Westbay MP System, ER-SOP-06.32, Rev.1., produced by Environmental Restoration Project, July 2002.

Campanella, D. (1999). Geo-Environmental Characterization of Soils Using In-Situ Testing Methods. Paper of the Asian Institute of Technology 40th Conference, New Frontiers & Challenges, Nov. 1999.

EnviroEquip (2001). Introduction to bailers. EnviroEquip Product News, August 2001 (www.enviroequip.com/quipnotes/Bailers.htm).

EnviroEquip (2002). Performance Comparison: Direct-Push Wells Versus Drilled Wells. EnviroEquip Product News, May 2002 (www.enviroequip.com/quipnotes/directpushVcontent.htm).

EPA, 1996, Environmental Investigations Standard Operating Procedures and Quality Assurance Manual, 1st Revision: March 1997.

Kearl, P.M., Korte, N.E., and Cronk, T.A., 1992, Suggested modifications to ground water sampling procedures based on observations from the colloidal borescope: Ground Water Monitoring Review, v. 12, no. 2, p. 155-160.

Kearl, P.M., Korte, N.E., Stites, M., Baker, J., 1994, Field comparison of micropurging vs. traditional ground water sampling: Ground Water Monit. Remed., vol. 14, no. 4, pp. 183-190.

Kansas Geological Survey (2002). Ground Water – Artesian Conditions. Finney and Gray County Geohydrology, Web Version April 2002 (URL=http://www.kgs.ku.edu/General/Geology/Finney/06_gw3.html)

Newall, J.: Groundwater Monitoring with the Waterra Inertial Pump ([http://www.waterra.com/pages/techpapers/TechA\(Groundwater%20Monitoring\)/techA1.html](http://www.waterra.com/pages/techpapers/TechA(Groundwater%20Monitoring)/techA1.html)).

Puls, R.W., and Powell, R.W., 1992, Acquisition of representative ground water quality samples for metals: Ground Water Monitoring Review 12, no. 3: 167-76.

Puls, R.W., and Barcelona, M.J., 1996, Low-flow (minimal drawdown) ground-water sampling procedures: Washington, D.C., U.S. Environmental Protection Agency, Office of Solid Waste and Emergency Response, EPA Ground Water Issue, EPA/540/S-95/504, 12 p.

Ritchey, J. (2002). Low-Flow Purging The Sampling Groundwater – Evolution of Technology and Standards. ASTM Standardization News, April 2002.

Robertson GeoConsultants Inc. (2002). Standard Operating Procedures (SOP5) for Groundwater Sampling.

Sevee, JE; White, CA; Maher, DJ, 2000, An Analysis of Low-Flow Ground Water Sampling Methodology: Ground Water Monitoring and Remediation, vol. 20, no. 2, pp. 87-93.

Torstensson, B.A. (1984). A New System for Ground Water Monitoring. Groundwater Monitoring Review, Fall 1984, pp. 131-138.

USGS, 2002. An Investigation of Baseline and Pre-Mining Groundwater Quality in the Red River Valley Basin, New Mexico – Field Sampling Plan for Groundwater Monitor Wells, Version 1.0 – April 30, 2002, prepared b the USGS, Central Region.

Westbay Instruments Inc., 1992: Multi-Level Groundwater Monitoring with the MP System, 20 pages.

Wilde, F.D., and Radtke, D.B, 1998, National field manual for the collection of water-quality data--Field measurements: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, variously paged.

Wilde, F.D., Radtke, D.B., Gibs, Jacob, and Iwatsubo, R.T., 1999, National field manual for the collection of water-quality data--Collection of water samples: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A4, 152 p.

Zemo, D.A., Y.G. Pierce, and J.D. Gallinatte (1992). Cone Penetrometer Testing and Discrete-Depth Groundwater Sampling Techniques: A Cost-Effective Method of Site Characterization in a Multiple Aquifer Setting, Proc. 6th Outdoor Action Conference, National Groundwater Association, May, Las Vegas.