EVALUATION OF THE MICROPURGE (LOW-FLOW) METHOD TO THE PACKER METHOD OF GROUNDWATER SAMPLING OF FRACTURES IN CRYSSTALLINE BEDROCK OF THE NORTH GEORGIA PIEDMONT

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Abstract. In recent years, the micropurge (or low-flow) method of collecting groundwater samples has become popular. The advantages of the method include low cost of purge water disposal due to small volumes, minimal colloidal material in the samples, and shorter sampling time. The method assumes that water will flow horizontally from the formation to the pump in the well with minimal mixing of casing water. Normally it is limited to use in wells with short screens, and pump rates low enough to minimize drawdown and volatilization of contaminants. Puls et al. (1996) recommends the use of packers for wells with long screens or open borehole fractured bedrock wells. Without the use of packers, the risk of spreading contamination to clean portions of the aquifer is high. In a fractured-bedrock aquifer at a contaminated site near Danielsville, Georgia, groundwater samples were collected from fractured-bedrock wells using the micropurge method and the packer method. Comparison of the two methods indicate that formation water was not sampled when the micropurge method was used.

INTRODUCTION

The objective of micropurge sampling is to minimize disturbance to the aquifer, and avoid high velocity fluid movement that could potentially entrain colloidal material that is otherwise immobile. Colloidal material, which is sometimes seen in groundwater that is sampled by the conventional method of removing three to five well volumes, can be charge coupled to organic molecules and metals (Puls et al., 1996). The groundwater sample may not be representative of true aquifer conditions because the sampling method caused otherwise immobile particles to be entrained and sampled.

The micropurge method has been implemented at a wide variety of contaminated sites encompassing a number of hydrologic conditions. The micropurge method uses a low-flow pump, such as a bladder pump or a pneumatic pump, that has the intake positioned at the middle of the well-screen interval that spans the aquifer or segment of aquifer that is to be sampled. The groundwater is withdrawn from the monitoring well at low flow rates until indicator parameters have stabilized, and formation water is present in the well screen.

The micropurge method has also been shown to be cost effective when sampling groundwater wells that have long screens or borehole lengths, such as fractured bedrock wells, which can have open-borehole lengths in excess of 100 feet. The cost for disposal of the wastewater from these wells can be expensive. The intake of the pump system is positioned at the opening of the particular fracture that is to be sampled. The pump is adjusted to a low flow rate, and the water that enters the pump system after stabilization of indicator parameters is assumed to be representative of the formation water in the fracture.

This paper will evaluate the micropurge method by comparing it to the use of isolation packers for collecting groundwater samples from open-borehole fractured-bedrock wells, and determine which measured field parameters are best for indicating that formation water is present in the well screen.

LITERATURE REVIEW

Puls et al. (1996) refers to micropurge “as the velocity with which water enters the pump intake and that is imparted to the formation pore water in the immediate vicinity of the well”. The objective is to minimize the disturbance to the aquifer that is being sampled. They emphasize that the micropurge technique is only effective when used in conjunction with their guidelines. They assert that the groundwater sample will be drawn directly from the formation, with little or no mixing with the casing/borehole water. This implies that the method could
be used for any screen length, including open-borehole bedrock wells.

The advantages to this method of groundwater sampling are minimization of adverse effects on sample quality such as colloidal material, sample variability, and minimization of waste water. Two disadvantages to the method include long-screen lengths which can influence unwanted regions of the aquifer, and higher initial cost for equipment if dedicated systems are used. A limitation of the method is the presence of air in the water column due to overpumping, which can cause the loss of volatile components of contaminants and the precipitation of metals.

In some circumstances, according to Puls, the micropurge method may not be the appropriate method to use. One such situation is the sampling of fractured-rock aquifers. Groundwater samples may not accurately represent fracture chemistry because the open borehole spans several fracture zones. Puls recommends using packers in conjunction with the micropurge method to aid in collecting representative samples, thus reducing the volume of groundwater that must be purged prior to collecting a sample.

Reilly et al. (1989) and Church et al. (1996) both found that long screen lengths can sample across multiple zones of permeability. Reilly showed that wellbore vertical velocities can significantly affect contaminant concentrations. Church et al. (1996) showed that long-screen wells resulted in average values for contaminants, and provided a possible pathway for cross contamination from one zone to another. Short-screen interval, low-volume wells allowed the sampling of the most contaminated sections as well as the uncontaminated sections of the aquifer without providing possible contaminant transport pathways.

One of the main advantages of the micropurge method is the low occurrence of colloidal material. Backhus et al. (1993) used the micropurge technique to study the effects of mobile colloids as a method of transport for contaminants such as polycyclic aromatic hydrocarbons (PAHs), polychlorinated biphenyls (PCBs), radionuclides, and metals. They found that under high pumping conditions some colloidal material that was otherwise immobile was entrained in the sample. The micropurge method utilizes low pumping rates and keeps colloidal material to a minimum.

Indicator parameters such as pH, specific conductance, temperature, dissolved oxygen, oxidation-reduction potential, and turbidity should be monitored during purging to ensure that formation water is being sampled. Temperature and pH should not be used to distinguish formation water from stagnant casing/borehole water (Puls et al., 1996).

Barcelona et al. (1994) showed that insufficient well screen purging, from either long- or short-screen intervals, led to an underestimation of the volatile organic compound concentration (VOC) by as much as 15 to 23%. It was concluded that the initial lower concentration was due to outgassing of the VOCs within the well borehole.

METHODS AND MATERIALS

The open-hole bedrock well used in this study was installed in 1997 using air-hammer drilling techniques, and is 220 feet. A variety of borehole geophysics such as caliper logs, borehole radar, and borehole televiwer were used to determine the locations of fractures within the open-hole bedrock well.

A dedicated micropurge pneumatic well sampling pump equipped with teflon hose was lowered to the appropriate depth of the fracture. The flow rate was regulated at 0.11 gpm. pH, temperature and specific conductance were measured during sampling of the fracture water in order to establish stabilization of the water chemistry. Groundwater samples were collected for total suspended solids, total dissolved solids, and total alpha activity after stabilization of pH, temperature, and specific conductance to within 10% for two consecutive readings.

Inflatable packers were used to isolate the fracture from borehole water, and possible dilution from other fracture waters. The packers were lowered to depths above and below the fracture that was to be sampled, and the packers were inflated to approximately 60 psi. The packers were equipped with pressure gauges, and then left in the well for 24 hours. The packers remained inflated, and groundwater sampling began.

A pneumatic pump was suspended between the packers at the depth of the fracture. The volume between packers was calculated from the diameter and the length of the borehole between the packers. A minimum of three packer volumes were used as a target for ensuring that the groundwater within the packer interval consisted of formation or fracture water. The pump rate used for removal of the groundwater was 0.33 gpm. pH, temperature, specific conductance, dissolved oxygen, and total alkalinity were measured in the field during purging. Groundwater samples were collected and analyzed for total suspended solids, total dissolved solids, and total alpha activity by liquid scintillation.
RESULTS AND DISCUSSION

The total purge volume removed from the well using the micropurge technique was approximately five gallons. One packer volume was purged from the well every 114 minutes during the packer method of groundwater sampling. One packer volume was equal to 38.25 gallons, and approximately 4.2 packer volumes of groundwater were removed from the well. This is similar to the conventional method of removing three to five well volumes in order to get a sample that is considered to be representative of formation groundwater. It is not clear how representative are the groundwater samples collected by the micropurge or packer method, or how reliable the convergence to a value (±10%) for the indicators used.

The pH of the samples collected from the well by the packer method range from 5.0 to 6.0, whereas the pH values for the micropurge method range from 7.0 to 8.0. This difference is attributed to the influence of borehole water, and possible mixing of waters from other fractures. CO₂ degassing will increase the pH. Although the micropurge method and the packer method of sample collection were performed one month apart, the pH values should not have been so dissimilar.

The pH of the groundwater collected using the packer method decreased to a pH of 5.0 before stabilization. If the later pH readings are compared to the first two readings using this method, formation water was being diluted with the water stored in the borehole. The purge time required until a representative formation groundwater sample can be collected will vary with the pumping rate. The pH results from the packer test seems to indicate that collection of a representative groundwater sample from a fracture in bedrock requires a longer purge time than indicated by the micropurge method.

Temperature measurements recorded during the two methods of groundwater sampling suggest that the water present in the well immediately after pumping began was formation water. Temperature increased during micropurging after 20 minutes. However, the temperature remained constant at 16°C during purging using the packer method, and temperature cannot be used as a stabilization parameter. This is not the case for the other measured parameters. Also, temperature may not be a good indicator of formation water in fractured bedrock wells where the well casing is constructed of stainless steel. Stainless steel casings are excellent conductors of heat, and the sample temperature will be influenced as it is collected.

Total Dissolved Solids (TDS) concentration, measured after the micropurge method was performed, was approximately 143 ppm. The total suspended solids (TSS) concentration was 21 ppm. The TSS concentration from the packer method appeared to reach an asymptotic level of about 5 ppm. The specific conductance measured during the packer method stabilized to approximately 120 to 125 μS/cm after 30-60 minutes. The specific conductance measured during micropurging was stable immediately after pumping began. The TDS concentration did not stabilize during the packer method, but fluctuated between 100 and 120 ppm. The TDS concentration should be approximately 60% of the specific conductance (Hem, 1985). The lower acidity of the bedrock waters (pH 5.0 to 6.0) is due to soil CO₂ and recharge waters from precipitation which contain primarily carbonic acid, derived from solubility of CO₂, as well as acid gases SO₂, NO₂, and NO (Langmuir, 1997). The excess of H⁺ ion from the dissociation of these acids will cause weathering of the silicate minerals in the bedrock, producing SiO₂ (silica). The silica concentration will contribute to the total concentration of TDS, but it is a non-conducting species, and will not contribute to the specific conductance of the bedrock waters.

Total alpha activity was measured after completion of the micropurge method, and from samples collected during the packer method. The total alpha activity stabilized to within ±10% on multiple consecutive readings after 120 minutes. The final result of the total alpha activity using the packer method was approximately 3500 pCi/L ± 148.76 pCi/L. Groundwater collected using the micropurge indicates a total alpha activity of approximately 467 pCi/L ± 46 pCi/L, which is similar to the concentration for the first sample collected using the packers method (670 pCi/L ± 63.12 pCi/L). This indicates that the micropurge groundwater samples may be representative of borehole water: a weighted average of the total alpha activity from each fracture, plus well losses of alpha emitting radionuclides such as Radon-222 by outgassing within the borehole.

A dilution factor of 5.22 is obtained by taking the ratio of the total alpha activity at the end of the purge time to the initial purging time of the packer method. The total alpha activity consists of radon-222 (gas), polonium-218 (metal), and polonium-214 (metal). Borehole dilution of these three radionuclides is always occurring due to reduced partial pressure within the borehole, and because the metal radionuclides electrostatically sorb onto charged surfaces such as the sides of the borehole, iron and manganese oxyhydroxides, clays (Langmuir, 1997), and
other charged particles. The reduced partial pressure within the borehole allows the radon to degass into the atmosphere (Barcelona, et al., 1994). The calculated dilution factor of 5.22 implies that approximately five volumes of water must be removed in order to obtain a groundwater sample that is representative of formation water from the fractures.

Dissolved oxygen data was collected during the packer method of groundwater sampling, although dissolved oxygen was not measured during the micropurge method of groundwater sampling. The first sample collected during the test was above the range of the instrument (>880 µg/L). The data show that the dissolved oxygen did not begin to stabilize until 300 minutes, and had not fully stabilized at the end of the purge time. The results of the dissolved oxygen measurements would seem to support the dilution factor of five calculated using the total alpha activity. For this well, dissolved oxygen appears to be a good stabilization indicator.

Total alkalinity was measured during purging of the packer method. The alkalinity should be decreased with respect to other natural waters because of the low concentration of HCO$_3^-$, and the acid nature of the bedrock waters. The total alkalinity does not appear to stabilize at any time during the purging using the packers, and is not a good parameter for determining formation water at this site.

CONCLUSIONS

From the results of this study, it appears that the micropurge method is valid for sampling of small-volume, short-screened wells, where there is the possibility of entraining colloidal material. Contaminants can be significantly different at various places along the borehole or screen, due to potential vertical groundwater flow gradients (Reilly et al., 1989; Church et al., 1996), thermodynamic gradients, and convection gradients in long boreholes or screens which contain large volumes of groundwater, or intersect more than one zone of permeability, including multiple fractures. Vertical flow gradients can exist because each individual fracture may be at a different head depending upon the location of the fracture origin. If the bedrock well intersects more than one fracture, then packers should be used to isolate the fractures in order to obtain representative groundwater samples (Puls et al., 1996). Nested independent wells are the best option to limit cross contamination. Packers will not work in screened wells because groundwater and dissolved contaminants may travel around the packer via the sandpack, and result in cross contamination.

pH, temperature, total dissolved solids, total suspended solids, and total alkalinity are not good indicators of formation water for large volume wells such as fractured-bedrock wells or long-screened wells. The best indicator parameters that can be used in the field are dissolved oxygen and specific conductance.

The total alpha activity measured for the borehole and the fracture worked quite well to determine the amount of dilution occurring in the borehole. This analysis and measurement could actually be performed on each well prior to collection of groundwater samples, and used as guide for determining the number of packer volumes that must be removed, prior to sampling.

REFERENCES


Puls, R.W., and Barcelona, M.J. 1996. Low-flow (minimal drawdown) ground-water sampling procedures. EPA/540/S-95/504.