Suggested Modifications to Ground Water Sampling Procedures Based on Observations from the Colloidal Borescope

by Peter M. Kearl, Nic E. Korte, and Tom A. Cronk

Abstract

Observations of colloidal movement under natural conditions and during pumping were conducted at several field sites. Results indicate that several modifications to present sampling protocols may improve the representativeness and cost effectiveness of obtaining ground water samples for assessing the total mobile contaminant load. These modifications include the installation of dedicated sampling devices, limited purging of the well prior to sampling, sampling at a flow rate of 100 mL/min, and no filtering of samples. This sampling approach can result in significant cost savings while providing the best possible water samples.

Introduction

For more than two decades, the technical literature has presented many arguments and counter-arguments regarding the basic principles involved in obtaining a representative water sample from a monitoring well. Controversial aspects of well sampling include purging, filtration, and pumping rate. In the work described in this paper, these controversial items are re-examined, this time by means of direct observation in the borehole using a newly developed device, the colloidal borescope.

Representative samples are essential for accurately assessing the presence and mobility of contaminant species in ground water. For an assessment of mobility, all mobile species, both dissolved and suspended particles, must be considered (Puls and Barcelona 1989). Recent studies, therefore, have focused on the role of suspended particles or colloids in the transport of highly adsorptive contaminants. As described by McCarthy and Zachara (1989) and Puls (1990), colloidal material (generally considered to be particles with diameters less than $10\,\mu m$) may be released from the geologic matrix and transported large distances. These authors reviewed numerous studies detailing the transport of metals, organic compounds, and radionuclides adsorbed to colloidal particles. These papers demonstrated that sampling technique must be capable of obtaining representative samples for both dissolved and colloidal-phase contaminants in evaluating the total mobile load.

Ground water sampling procedures, including purging, sampling, and filtering, are discussed by Schuller et al. (1981), Scalf (1984), Korte and Kearl (1985), Barcelona et al. (1985), and the U.S. Environmental Protection Agency (1986). Present ground water sampling protocol recommends that wells be purged a minimum of three well volumes prior to sampling. According to Barcelona et al. (1985), water that remains in the well casing for extended periods of time has the opportunity to exchange gases with the atmosphere and to interact with the well casing material. Consequently, the chemistry of water stored in the well casing is unrepresentative of the aquifer. Herzog et al. (1988) have also reported that purging is necessary in slowly recovering wells to obtain representative samples of organic contaminants in ground water.

Other studies have questioned the reliability of purging criteria. Gibs and Imbrigiotta (1990) evaluated well-purging criteria and concluded, ". . . none of the previously recommended criteria for purging a well can be applied reliably to collecting a representative sample of purgeable organic compounds." Robin and Gillham (1987) demonstrated that purging was unnecessary under the conditions of their experiment, i.e., permeable geologic materials and non-reactive tracers, because ground water in the screened portion of the well was representative of the aquifer. Pionke and Urban (1987) state that very little purging is needed if the water level is below the casing in an open borehole.

Concerns have also arisen that sampling techniques may alter natural ground water quality. This is a particular concern with regard to colloid concentrations. McCarthy and Wobber (1986) point out that increased flow rates resulting from pumping for sampling purposes may mobilize colloids sorbed to the aquifer material or trapped in low flow zones and bias chemical analysis results. To minimize these impacts, Puls and Barcelona (1989) recommend a sampling pumping rate of 100 mL/min. Using this same pumping rate, Ryan and Gschwend (1990) showed that 10 to 20 well volumes were necessary to obtain stable colloid concentrations. This purging required three to six hours to complete for each monitoring well.

To minimize disturbances in the well and surrounding aquifer and to prevent mixing of stagnant water in the well casing with water in the well screen, Robin and

Gillham (1987) recommend the permanent installation of tubing for a syringe sampler or a positive displacement pump near the base of the well screen. Pumped at a low volume, these dedicated sampling devices would eliminate well purging and greatly reduce sampling time and cost.

Another questionable aspect of sampling protocol is whether to filter ground water samples for chemical analysis. Guidance provided by the regulatory agencies more than 20 years ago (EPA 1971) was that water samples should be filtered through a 0.45 μm filter in order to determine the difference between suspended and dissolved species. This guidance persisted, though it was shown that some suspended matter passed through a 0.45 μm filter (Kennedy et al. 1974, Wagemann and Brunskill 1975). More recently, "total" analyses have been advocated in which the water sample is not filtered. Recent experience of the authors with the regulatory community has demonstrated that the controversy is far from settled and that regulatory agency personnel, in general, prefer total analyses in order to avoid missing potentially important data. The resulting water and sediment sample is digested and analyzed as a single sample.

Monitoring wells are sometimes screened in silty or clayey zones, and samples may have substantial amounts of fine sediment that may bias a sample (Braids 1987). Indeed, it has been further stated that "field filtration will provide the same quality filtrate for chemical analysis negating inconsistent sampling protocols" (Burger 1987).

A different view has been presented by Ryan and Gschwend (1990), who demonstrated that the characterization of the mobile contaminant load should not rely on separation by filtration. Puls and Barcelona (1989) also recommend no filtration for the determination of mobile metal ions if extraneous sources of particles are removed by careful well construction and development. These authors further suggest that a bladder pump, because of its relatively low flow rate, would not disturb colloids sorbed to the well casing, screen, sand pack, or aquifer material but would sample only the naturally migrating colloidal particles. Other investigators have used chemical analyses to demonstrate the effects of suspended solids on filtered and unfiltered samples (Strausberg 1983).

In order to resolve these issues of obtaining a representative sample of natural ground water, the colloidal borescope was used to assess the effects of purging, sampling, and filtering from a hydrodynamic viewpoint. This borescope is an in situ device that provides direct visual means for observing colloids in monitoring wells. Colloidal size, density, and flow patterns can be assessed, and an evaluation of sampling impact on the natural ground water flow system can be determined. Results from the colloidal borescope obtained at several field sites and their implications for present sampling techniques are presented.
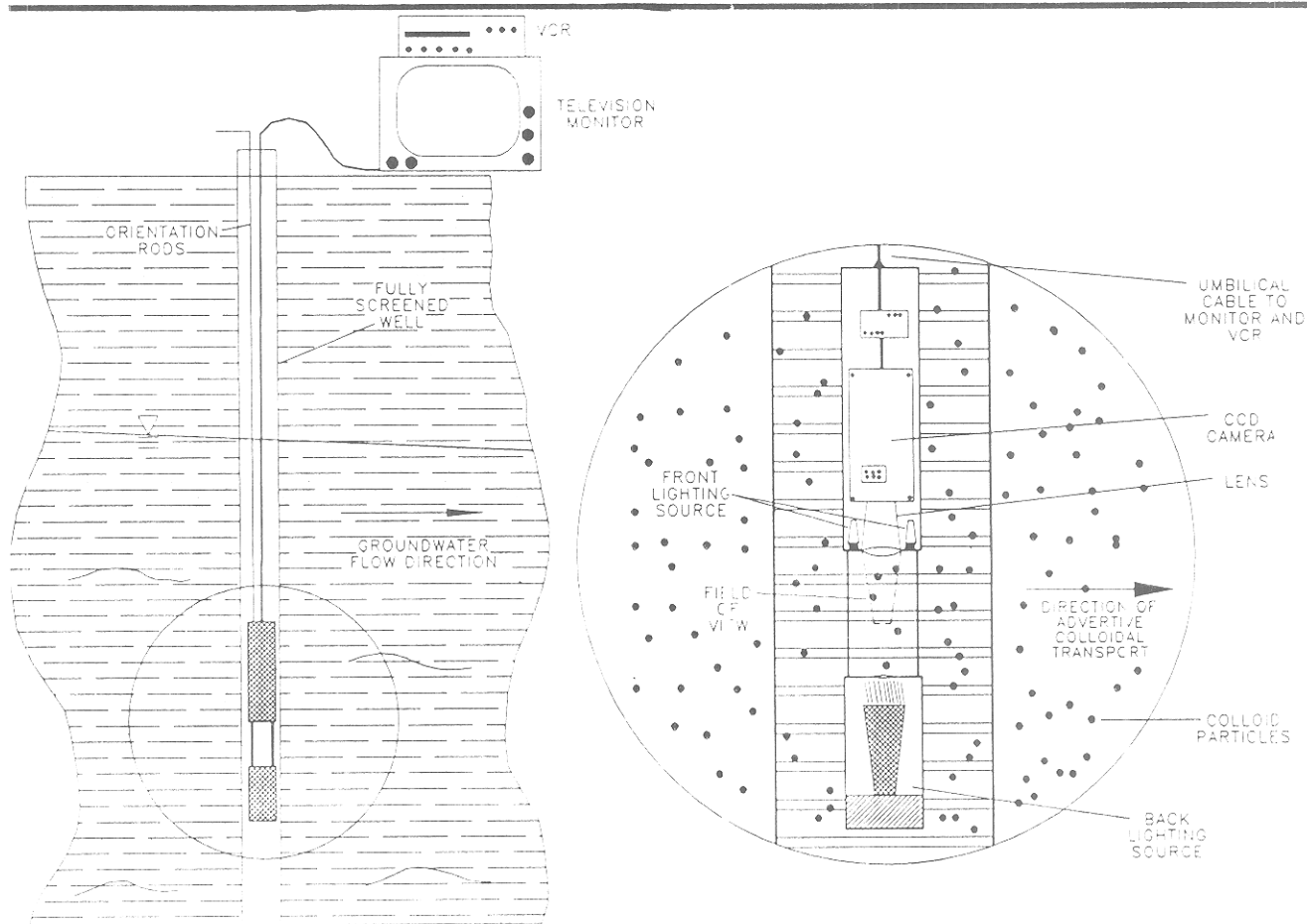

Figure 1. Schematic diagram of the colloidal borescope.

Instrument Description

The colloidal borescope was developed at Oak Ridge National Laboratory as part of the Exploratory Studies Program. The instrument consists of a CCD (charge-coupled device) camera, optical magnification lens, illumination source, and stainless steel housing. The device is approximately 60 cm long and has a diameter of 44 mm, facilitating insertion into a 5 cm-diameter observation well (Figure 1). After insertion into the observation well, the electronic image is transmitted to the surface by a 33 m umbilical cable, where it is viewed on a 25 cm monitor and recorded on VHS tape for further analysis. The magnified image recorded on the VHS tape corresponds to a field of view of approximately 1.0 mm × 1.4 mm × 0.1 mm. A similar device has been developed simultaneously and is referred to as a Ground Water Azimuth Detection System (Foster and Fryda 1990).

The colloidal borescope is inserted into the monitoring well by a set of rigid quick-connect tubes. These tubes maintain the alignment of the borescope in the well so that flow directions can be determined. The rigid tubes and borescope are maintained in a fixed position in the well by a clamp at the surface.

Results and Discussion

The colloidal borescope was initially tested on a laboratory sand tank and the results presented in Kearl et al. (1991). A field version of the borescope was then tested at four field sites: Grand Junction, Colorado; Kansas City, Missouri; Georgetown, South Carolina; and Elizabeth City, North Carolina. At the Grand Junction site, the aquifer consists of Gunnison River deposits of gravel, sand, and silt. There are only traces of organic material and minor amounts of clay. The alluvial aquifer at Kansas City is a clayey silt unit with minor amounts of organic material and substantial quantities of clay. Both Carolina sites consist of coastal-plain sediments of fine- to medium-grained sand. The Georgetown site has minor amounts of clay but is located in a swampy environment with substantial quantities of organic mate-

rial. The Elizabeth City site has some clay and only minor amounts of organic material. Both 5 and 10 cm-diameter monitoring wells were tested at the Grand Junction and Elizabeth City sites. Only 5 cm wells were tested at the remaining sites. Monitoring wells at all sites were installed and developed using conventional techniques.

The colloidal borescope was slowly inserted into the well to the desired depth. All measurements were made within the screened interval. The rigid tubing was clamped at the surface to maintain the orientation of the instrument in the well.

During the installation of the borescope, a massive disturbance of the flow field was observed (Figure 2). This disturbance was typified by turbulent flow with numerous colloidal and larger-sized particles. The view was similar to a snow blizzard. The larger-sized particles are believed to be debris from the well screen or casing. This observation was consistent at all of the field sites regardless of how carefully the borescope was inserted into the well.

This massive disturbance observed by the colloidal borescope would be typical of the disturbance encountered when installing a sampling pump. A sampling tube might cause less disturbance while a bailer would create even more.

After varying periods of time ranging from a few minutes to approximately 30 minutes, turbulent flow ceases, and horizontal laminar flow becomes dominant (Figure 2). This horizontal flow is in the same direction as the local ground water flow. Observations after 72 hours have shown that the flow remains consistent at a uniform velocity. Given the consistent flow direction and the observed flow velocity, colloids observed after several hours must have originated from the upgradient porous media (Kearl et al. 1991).

While the flow velocity stabilizes rather quickly, the colloidal density varies significantly with time. Maximum density is observed upon initial insertion of the borescope into the well bore. This density gradually decreases with time, even after horizontal laminar flow
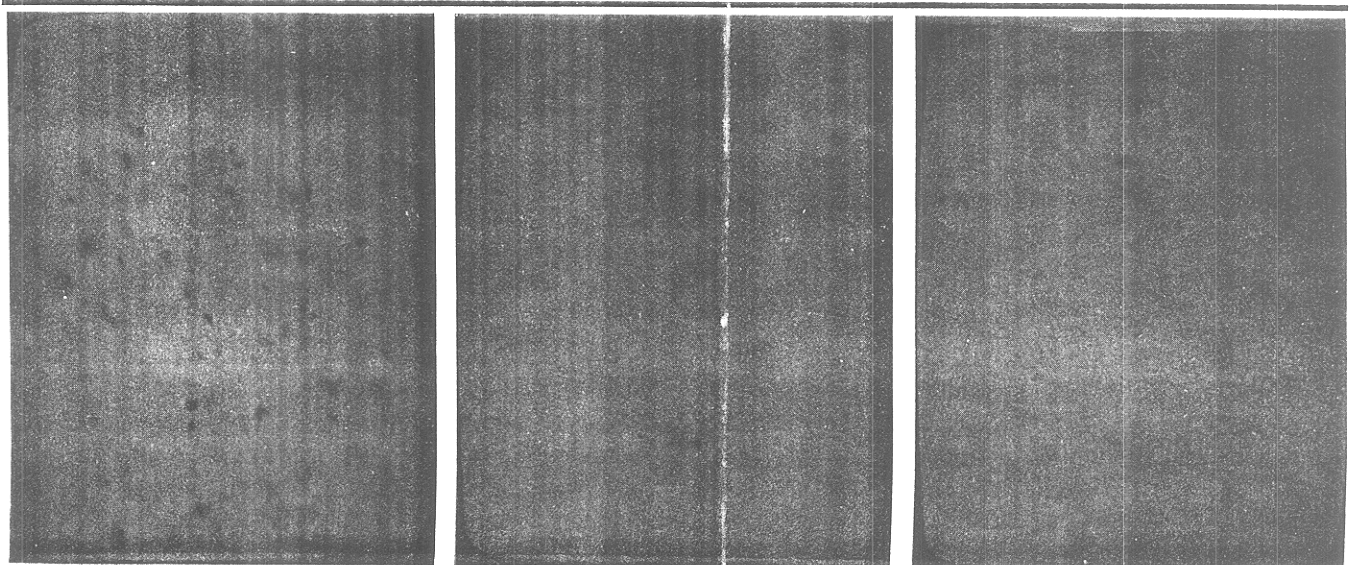

Figure 2. Photographs of colloids in a well at Grand Junction site after the installation of the instrument (A), after a stable laminar flow field has been established (B), and 24 hours after the instrument was installed (C).

dominates the system. At the Grand Junction site, hundreds of colloidal particles were present in the field of view six hours after the borescope was inserted into the well. After 24 hours, the colloidal density had decreased to only a single colloid visible every few minutes (Figure 2). This observation was consistent with those at the Elizabeth City and Georgetown sites. At the Kansas City site, however, the colloidal density decreased but remained in the hundreds of colloids range 24 hours after inserting the borescope into the well (Figure 3). This may be a reflection of the fine-grained nature of the aquifer in Kansas City.

The change in colloidal density has a significant impact on sampling. It has been reported, for example, that there is a strong inverse correlation between turbidity and representativeness of samples (Puls et al. 1991). After insertion of the borescope, or a sampling device for that matter, it takes several hours for colloid density, flow rate, and flow direction to stabilize. These observations suggest that insertion of a device into the well mobilizes colloids that are sorbed or trapped in low flow zones in the porous media. These colloids are not part of the natural colloidal density. Even if a well is pumped at 100 mL/min for three to six hours as recommended by Ryan and Gschwend (1990), a larger number of colloids may exist in the well than in the natural ground water due to insertion of the sampling device. One method to ensure a representative sample under these conditions is to dedicate the sampling device to the well to allow colloid density, velocity, and direction to stabilize. Our experience with the colloidal borescope suggests that this requires 24 hours.

The size range of naturally occurring colloids was estimated by comparing field observations with laboratory observations of commercially available microspheres of known size (Figure 4). Although the literature reports a large number of colloids in the 0.1 to 1.0 μm range (McDowell-Boyer et al. 1986), the results of these studies show that even after the colloidal density stabilizes, there are a significant number of colloids that are much larger in size. These particles are estimated to range up to 10 μm, with some colloids even larger. If particle size in ground water were evaluated by sample methods, the evidence would suggest that sampling may break the colloids into small size fractions. Filtering of water samples would certainly exclude these particles from analysis.

The last series of field tests conducted for this investigation involved an evaluation of the effects of sample pumping on ground water flow and colloidal density. At the Grand Junction site, a bladder pump and the colloidal borescope were installed in a 10cm-diameter well. The intake for the bladder pump was placed at the same depth as the field of view for the borescope. The equipment was allowed to reside in the well for 24 hours prior to pumping to allow equilibration of natural conditions. After 24 hours, the pumping rate was set at 100 mL/min as recommended by Puls and Barcelona (1989).

Results of the experiment indicate that pumping causes only a minor increase in the colloidal density.
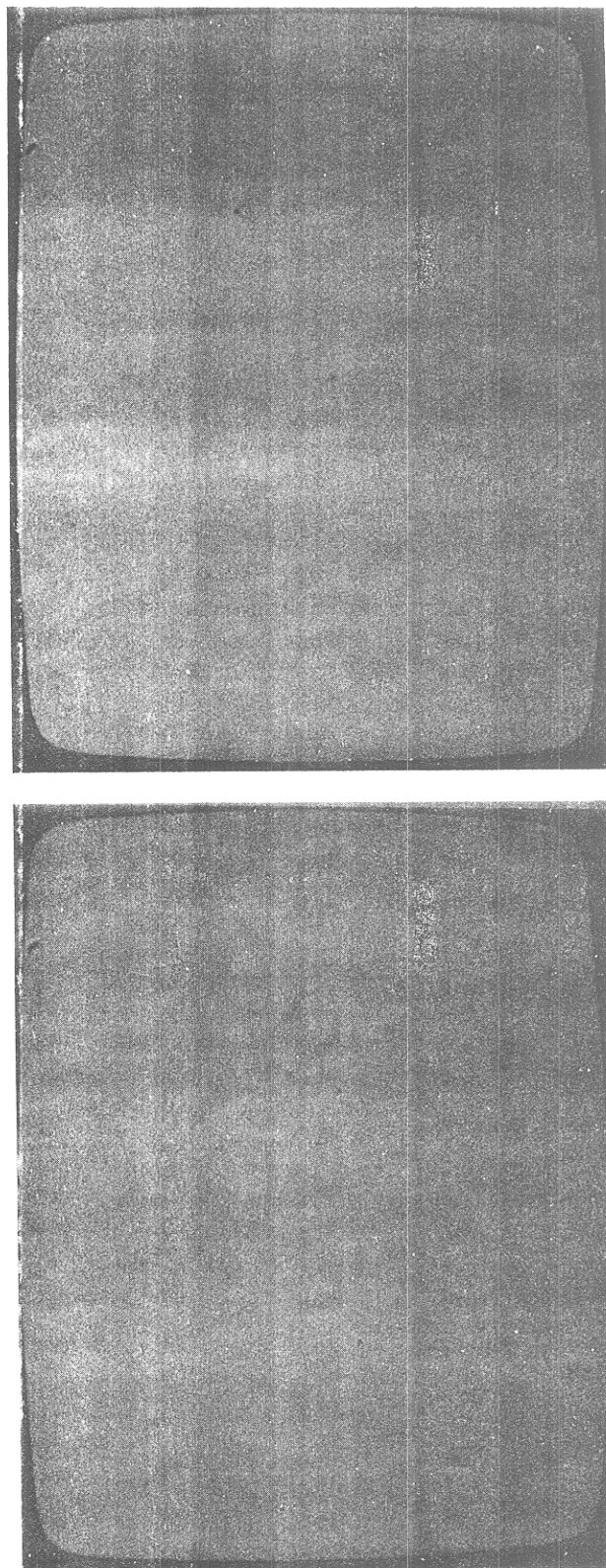

Figure 3. Photographs of colloids in a well at the Kansas City site after a stable laminar flow field has been established (A) and 18 hours after the instrument was installed (B).

One to two additional colloids every few minutes are observed as a result of pumping. The bladder pump causes a slight disturbance in the well due to the volumetric displacement as the bladder fills and empties. This displacement is evidenced by the rapid acceleration of colloids in the field of view. This pressure pulse does not appear to cause a significant disturbance in the formation surrounding the well as shown by the lack of

increase in colloidal density.

The second set of experiments to evaluate the effects of sample pumping were performed at the Elizabeth City site. For the first part of the experiment, the sampling tube for a peristaltic pump was taped to the borescope with the inlet directly adjacent to the field of view. The borescope was inserted into a 5cm-diameter well and allowed to sit overnight. The following morning, the density of colloids decreased to less than 100 in the field of view. The well was then pumped at a rate of 240 mL/min using the peristaltic pump. The colloidal density was estimated to increase by a factor of two.

The second part of the experiment at Elizabeth City consisted of placing the sampling tube inlet into the middle of a 1.6m length of screen and the colloidal borescope into the well casing above the screen. This experiment was designed to observe the influence of pumping on flow in the overlying well casing. The well was pumped at 270 mL/min using the peristaltic pump. Colloids were observed moving in the well in what appeared to be horizontal rotational flow about a vertical axis. There was, however, no evidence of turbulent or vertical flow as indicated by the particles occurring in the overlying well casing remaining in focus.

This observation suggests that natural ground water flow through the well screen was sufficient to supply adequate water for pumping. Calculations of the ground water discharge through the 1.5m screened interval using the observed flow velocity from the borescope (0.5 mm/min) in a 5cm-diameter well yields 37,500 mm/min. If a well is pumped at 270 mL/min, the amount is less than 1 percent of the available flow volume. Stagnant water in the well casing is, therefore, unaffected by the pumping if the pumping rate does not exceed recharge capabilities of the aquifer. This would agree with Robin and Gillham's (1987) observations for permeable aquifers that water in the well casing is not removed during sampling.

If horizontal flow dominates the screened interval and has no significant effect on water in the overlying well casing, then transport of atmospheric gases or degassing of ground water by diffusion is the only mechanism available to transport gases and affect ground water chemistry. Diffusion rate calculations, however, indicate that exchanges of gases between the atmosphere and the ground water is not a concern as suggested by Barcelona et al. (1985). The growth with time of the diffusive boundary layer δ, at the air/water interface is calculated to be $\delta \approx 2\sqrt{D_{AB}t}$, where D_{AB} is the binary diffusivity coefficient of gas A in solute B (cm^2/sec), and t is time (sec). If the time required for a water molecule to flow across the well is taken to be d/v, where d is the diameter of the wellbore (cm), and v is the ground water flow velocity through the well (cm/s), and the Stokes-Einstein equation is used to estimate the gaseous diffusivity coefficient in water at approximately 10^{-5} cm^2/sec (Bird et al. 1960), the maximum thickness of the diffusive boundary layer is found to vary between 6.0cm and 0.6cm for wellbore flow velocities of 1 m/yr and 100 m/yr, respectively. Under these conditions, gaseous exchange is indeed minimal.
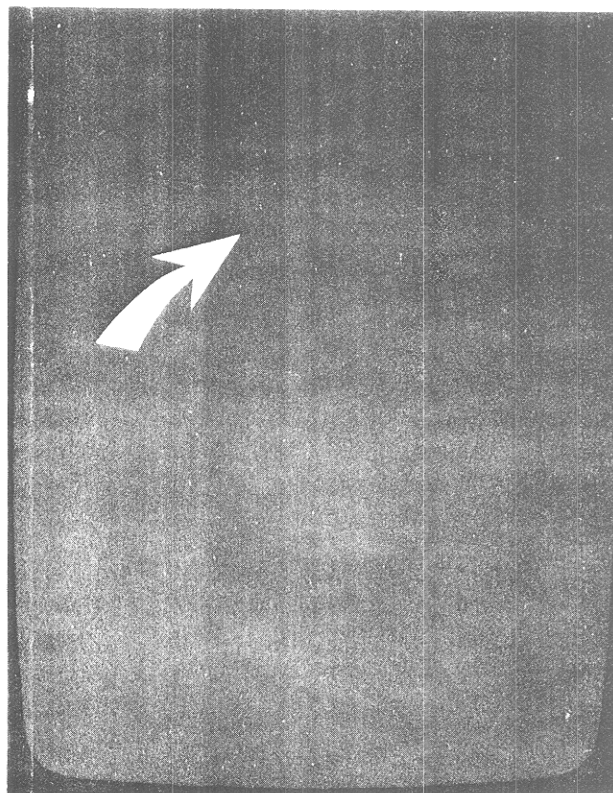

Figure 4. Arrow points to a microsphere that is 3.2 μm in diameter.

Summary and Conclusions

Direct observations of colloidal movements in monitoring wells suggests that modifications to present sampling procedures are necessary to obtain representative ground water samples for accurately assessing mobile contaminant species. From a hydrodynamic standpoint, water samples should be obtained in the following manner: wells should not be purged, water samples should be taken from dedicated sampling lines or pumps with intakes in the screened interval and at flow rates of 100 mL/min, and water samples should not be filtered.

Experimental results have shown that insertion of a device similar to a pump or bailer results in the mobilization of colloids sorbed to the surrounding formation. If purging is conducted at low flow rates as recommended by Ryan and Gschwend (1990), purging should be initiated no sooner than 24 hours after the sampling device has been installed.

Horizontal laminar flow observed in the well screen indicates that stagnant water in the well casing does not mix with water in the well screen. This observation agrees with Robin and Gillham (1987) that water in the well screen is representative of the natural ground water.

If dedicated sampling devices similar to those recommended by Robin and Gillham (1987) are placed in wells, disturbances and subsequent increases in colloidal densities resulting from inserting the sampler into the well are eliminated. By pumping these sampling devices at 100 mL/min as recommended by Puls and Barcelona (1989), there is no significant increase in the colloidal density.

It is possible that natural colloids could be a transport

mechanism for substantial concentrations of otherwise immobile contaminant species. Consequently, the final recommendation of this paper is that if wells are not purged and samples are taken from dedicated sampling devices at low flow rates, then representative water samples will be obtained. These samples should not be filtered when assessing the total mobile contaminant load.

Finally, it is important to note that considerable cost savings can be realized from this approach. By eliminating well purging prior to sampling, the savings of both the time involved with purging and the cost associated with purge-water disposal can be substantial. Additional chemical sampling investigations similar to the one conducted by Robin and Gillham (1987) are recommended to further evaluate the best procedures for obtaining representative water samples.

Acknowledgments

References

Barcelona, M.J., J.P. Gibb, J.A. Helfrich, and E.E. Garske. 1985. *Practical Guide for Ground Water Sampling.* Illinois State Water Survey Report 374, Champaign, Illinois.

Bird, R.B., W.E. Steward, and E.N. Lightfoot. 1960. *Transport Phenomena.* John Wiley & Sons, New York, New York.

Braids, O.C. 1987. Should ground water samples from monitor wells be filtered before laboratory analysis? Opinion I. *Ground Water Monitoring Review,* v. 7, no. 3, pp. 58–59.

Burger, R.M. 1987. Should ground water samples from monitoring wells be filtered before laboratory analysis? Opinion II. *Ground Water Monitoring Review,* v. 7, no. 3, pp. 59–63.

Foster, J.W. and L.J. Fryda. 1990. Ground Water Azimuth Detection, U.S. Patent #4,963,019.

Gibs, J. and T.E. Imbrigiotta. 1990. Well-purging criteria for sampling purgeable organic compounds. *Ground Water,* v. 28, no. 1, pp. 85–93.

Herzog, B.L., S.F.J. Chou, J.R. Valkenburg, and R.A. Griffin. 1988. Changes in volatile organic chemical concentrations after purging slowly recovering wells. *Ground Water Monitoring Review,* v. 8, no. 4, pp. 93–99.

Kearl, P.M., T.A. Cronk, and C.A. Little. 1991. Laboratory observations and measurements of colloidal velocity in a monitoring well. *Water Resources Research,* in review.

Kennedy, V.C., G.W. Zellweger, and B.F. Jones. 1974. Filter pore-size effects on the analysis of Al, Fe, Mn, and Ti in water. *Water Resources Research,* v. 10, no. 4, pp. 785–790.

Korte, N.E. and P.M. Kearl. 1985. *Procedures for the Collection and Preservation of Ground Water and Surface Water Samples and for the Installation of Monitoring Wells.* GJ/TMC-08, 2nd Ed., NTIS, U.S. Department of Energy Technical Measurements Center, Springfield, Virginia.

McCarthy, J.F. and F.J. Wobber. 1986. Transport of Contaminants in the Subsurface: The Role of Organic and Inorganic Colloidal Particles. Int. Series of Interactive Seminars, Summary Report, ORNL/M-349, Oak Ridge, Tennessee.

McCarthy, J.F. and J.M. Zachara. 1989. Subsurface transport of contaminants. *Environmental Science and Technology,* v. 5, no. 23, pp. 496–502.

McDowell-Boyer, L.M., J.R. Hunt, and N. Sitar. 1986. Particle transport through porous media. *Water Resources Research,* v. 22, no. 13, pp. 1901–1921.

Pionke, H.B. and J.B. Urban. 1987. Sampling the chemistry of shallow aquifer systems — A case study. *Ground Water Monitoring Review,* v. 7, no. 2, pp. 79–88.

Puls, R.W. and M.J. Barcelona. 1989. *Ground Water Sampling for Metals Analysis.* EPA/540/4-89/001, Robert S. Kerr Laboratory, U.S. Environmental Protection Agency, Ada, Oklahoma.

Puls, R.W. 1990. Colloidal considerations in ground water sampling and contaminant transport predictions. *Nuclear Safety,* v. 31, no. 1, pp. 58–65.

Puls, R.W., R.M. Powell, D.A. Clark, and C.J. Paul. 1991. Facilitated Transport of Inorganic Contaminants in Ground Water: Part II, Colloidal Transport, EPA/600/M-91/040, Robert S. Kerr Laboratory, U.S. Environmental Protection Agency, Ada, Oklahoma.

Robin, M.J.L. and R.W. Gillham. 1987. Field evaluation of well purging procedures, *Ground Water Monitoring Review,* v. 7, no. 4, pp. 85–93.

Ryan, J.N. and P.M. Gschwend. 1990. Colloid mobilization in two Atlantic coastal plain aquifers: Field studies. *Water Resources Research,* v. 26, no. 2, pp. 307–322.

Scalf, M.R. 1984. Sampling Procedures for Ground Water Quality Investigations. EPA-600/D-84-137, Robert S. Kerr Laboratory, U.S. Environmental Protection Agency, Ada, Oklahoma.

Schuller, R.M., J.P. Gibb, and R.A. Griffin. 1981. Recommended sampling procedures for monitoring wells. *Ground Water Monitoring Review,* v. 1, no. 1, pp. 42–46.

Strausberg, S. 1983. Turbidity interferes with accuracy in heavy metal concentrations. *Industrial Wastes,* v. 29, no. 2, pp. 16–21.

U.S. Environmental Protection Agency. 1971. Methods for Chemical Analysis of Water and Wastes. EPA Report 16020-07/71, Washington, D.C.

U.S. Environmental Protection Agency. 1986. *RCRA Ground Water Monitoring Technical Enforcement Guidance Document.* OSWER-9950.1, Office of Waste Programs Enforcement, Office of Solid Waste and Emergency Response, Washington, D.C.

Wagemann, R. and G.J. Brunskill. 1975. The effect of filter pore size on analytical concentrations of some trace elements in filtrates of natural water. *International Journal of Environmental Analytical Chemistry,* v. 4, pp. 75–84.

Biographical Sketches

P.M. Kearl received a B.S. in geology from Mesa State College in Grand Junction, Colorado, and an M.S. in hydrology/hydrogeology from the University of Nevada, Reno, Nevada. Currently he is a research scientist at Oak Ridge National Laboratory (Environmental Sciences Division, Grand Junction Office, Grand Junction, CO 81502). Kearl's primary research interest is the accurate quantitification of ground water velocity measurements. He is a Certified Ground Water Professional.

N.E. Korte received a B.S. in chemistry from the University of Illinois in Champaign-Urbana and an M.S. in analytical chemistry from the University of Arizona, Tucson, Arizona. Currently he is chemical projects manager at Oak Ridge National Laboratory (Environmental Sciences Division, Grand Junction Office, Grand Junction, CO 81502). Korte's primary research interest is studying the fate and effect of trace species in the environment. He is a Certified Hazardous Materials Manager and a Certified Ground Water Professional.

T.A. Cronk received his B.S. in physics from Mesa College in 1987 and has worked at Oak Ridge National Laboratory, Grand Junction Office, Grand Junction, Colorado (81502) for the past four years. Areas of specialization at ORNL/GJ include basic research addressing subsurface contaminant transport and the development of innovative environmental assessment/remediation technologies. Cronk is registered as an Engineer in Training and anticipates receiving his Professional Engineering credentials in early 1992.