

DISCRETE-LEVEL GROUND-WATER MONITORING SYSTEM FOR CONTAINMENT AND REMEDIAL PERFORMANCE ASSESSMENT OBJECTIVES

By Robert W. Puls¹ and Cynthia J. Paul²

ABSTRACT: A passive discrete-level multilayer ground-water sampler was evaluated to determine its capability to obtain representative discrete-interval samples within the screen intervals of traditional monitoring wells without purging. Results indicate that the device is able to provide such data for the inorganic contaminants and species analyzed in the study and provided more accurate estimations of contaminant distributions and mass in the vertical direction within a sandy Atlantic coastal plain aquifer, than "traditional" sampling methods.

INTRODUCTION

Until recently, the most common ground-water monitoring purposes or objectives have been for site assessment and remedial performance assessment. With more and more emphasis being placed on waste isolation or containment, natural attenuation, and in-situ remediation technologies, another monitoring purpose of increasing importance is the evaluation of contaminant detection, release, or breakthrough. Early detection of contaminant migration from source areas, containment zones, or in-situ reactive barriers is important to maximize the effectiveness of corrective measures. Experience has demonstrated the difficulty associated with extraction or cleanup efforts, particularly at sites where contaminant releases have gone undetected for many years.

Subsurface system heterogeneities, which include variations in geology, geochemistry, hydrology, and microbiology, have been shown to affect contaminant flow paths and cleanup efforts. These heterogeneities not only limit the effectiveness of remedial actions but also complicate the design, implementation, and interpretation of ground-water samples collected for different regulatory purposes. As available methods and tools for subsurface investigations have become increasingly sophisticated and the understanding of the subsurface environment has advanced, there is an awareness that in most cases a primary concern for site investigations and remedial designs is accurate characterization of contaminant flow paths and the design of monitoring systems that increase the probability of intercepting contaminant plumes. In many cases, plume thickness can be less than the well screen lengths [e.g., 3–6 m (10–20 ft)], which are typically installed to detect and monitor plume movement over time, resulting in misleading interpretations that may put the environment or human health at risk.

This paper presents the results of a multilayer ground-water sampler that is currently available for use in conventional monitoring wells to provide discrete-layer water samples for accurate vertical delineation of contaminant distribution and detection. The application of this monitoring system is "passive" and it is capable of contaminant detection over very short vertical distances [<5 cm (2 in.)]. The objective of this study was to compare sampling results using this device with two more traditional methods as well as to validate the accu-

racy of the samples collected with the multilayer sampler using newly developed hydraulically driven push-probe technology (Geoprobe) for discrete-level ground-water sampling. The study was conducted at a well-characterized site near Elizabeth City, N.C., where field-based site characterization and remediation research by the National Risk Management Research Laboratory (U.S. Environmental Protection Agency) has been ongoing since 1990. Monitoring Well 45 was sampled with an electric submersible pump using low-flow sampling techniques (Puls and Powell 1992; Puls and Paul 1995; Puls and Barcelona 1996) and with a bailer using standard three-well volume-purging methods. The well was sampled at the same time with a multilayer sampling system (DMLS, Margan Ltd.), whereby discrete-interval samples were collected passively in dialysis cells every 3.8 cm (1.5 in.). Finally, aqueous concentrations were determined in the formation pore waters immediately adjacent to the monitoring well studied using a Geoprobe equipped with 30 cm (12 in.) screens for water collection to validate the vertical concentration distribution of measured contaminant across the screened interval of the monitored well.

Site Description

The field site is located at the U.S. Coast Guard Support Center near Elizabeth City, N.C., about 100 km south of Norfolk, Va. and 60 km inland from the Outer Banks of North Carolina. The base is located on the southern bank of the Pasquotank River, about 5 km southeast of Elizabeth City. An old chrome-plating shop was located in a hangar, which is only 60 m south of the river (Fig. 1). Acidic chromate-laden liquid wastes were unknowingly discharged into the soils beneath the hangar for some time prior to the discovery of a hole in the plating shop floor. These wastes infiltrated the soils and impacted the underlying aquifer in contact with the adjacent river. The site geology has been described in detail elsewhere (Puls et al. 1994a,b). Ground-water flow velocity is extremely variable with depth, although a highly conductive layer generally persists at roughly 4–7 m (13–23 ft) below ground surface. This layer coincides with the highest aqueous concentrations of chromate. The ground water resides about 1.5–2.0 m (4.9–6.6 ft) below ground surface, depending upon rainfall inputs to upgradient agricultural fields.

SAMPLING MATERIALS AND METHODS

Monitoring Well 45

Well 45 is a 5 cm (2 in.) diameter, schedule 40 polyvinyl chloride (PVC) well with a 0.25 mm (0.010 in.) slotted, 3 m (10 ft) long screen, and the well is completed 7.3 m (24 ft) below ground surface. It was installed without a sandpack, allowing the natural formation to collapse back in as the hol-

¹Res. Soil Sci., Nat. Risk Mgmt. Res. Lab., U.S. Envir. Protection Agency, P.O. Box 1198, Ada, OK 74820. E-mail: puls@ad3100.ada.epa.gov.

²Envir. Sci., Nat. Risk Mgmt. Res. Lab., U.S. Envir. Protection Agency, P.O. Box 1198, Ada, OK.

Note. Associate Editor: Hilary I. Inyang. Discussion open until November 1, 1998. To extend the closing date one month, a written request must be filed with the ASCE Manager of Journals. The manuscript for this paper was submitted for review and possible publication on April/May, 1996. This paper is part of the *Journal of Environmental Engineering*, Vol. 124, No. 6, June, 1998. ©ASCE, ISSN 0733-9372/98/0006-0549-0553/\$8.00 + \$.50 per page. Paper No. 17664.

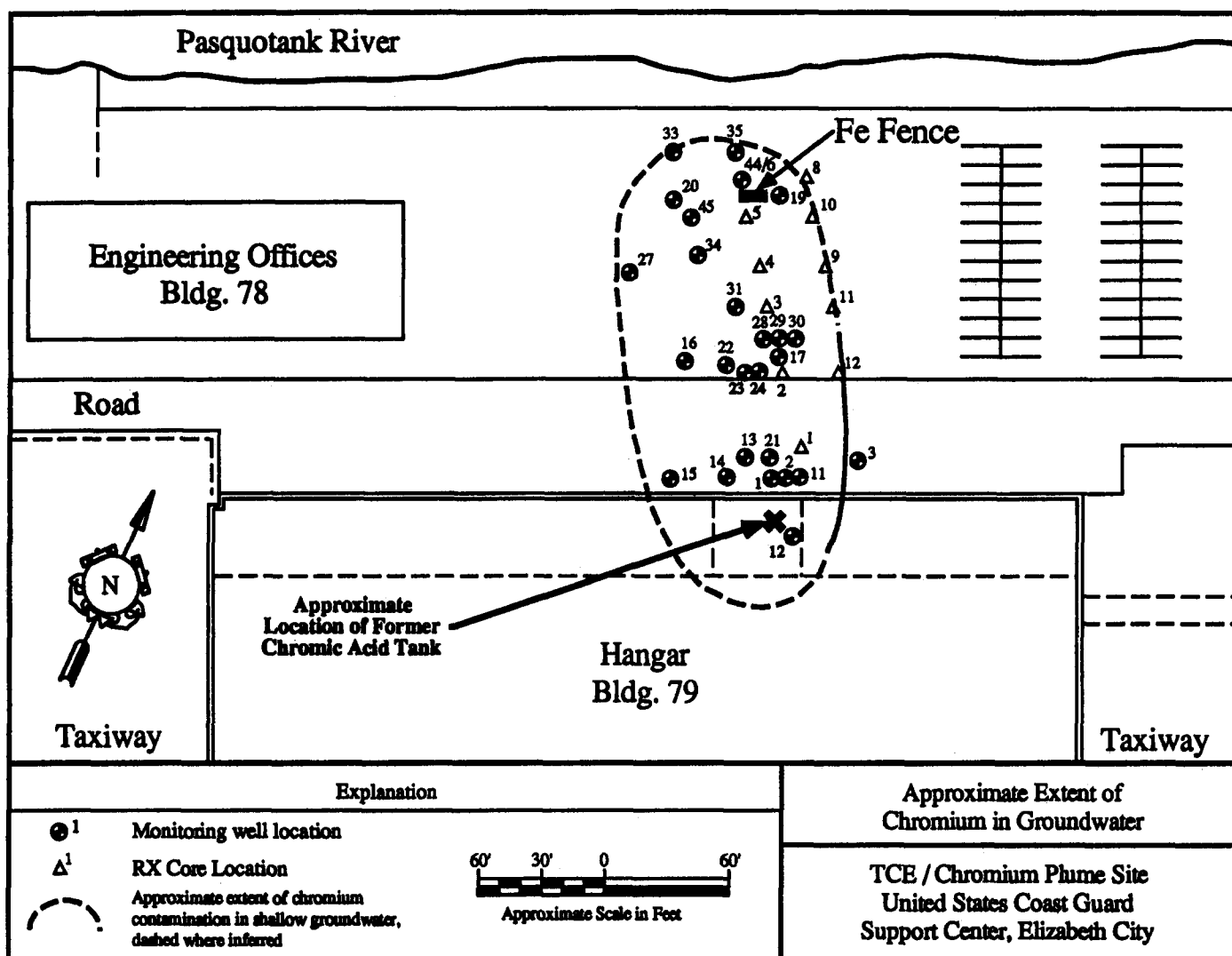


FIG. 1. Site Map Showing Extent of Chromium Plume, Plating Shop, Pasquotank River, and Well 45

low-stem augers were removed. The well was developed immediately after installation to a turbidity criteria of less than five nephelometric turbidity units (NTU) using an electric submersible pump that was lowered and raised throughout the screened interval to remove loose particulates and establish hydrologic contact between the well screen and an adjacent formation.

Sampling Devices

Four ground-water sampling devices were used in the study. A Grundfos Redi-Flo2 electric submersible pump was used to sample the wells using low-flow purging techniques (Puls and Barcelona 1996). A Teflon bailer with 0.7-L capacity was used to sample the same wells. A discrete multilayer sampler (DMLS, Margan Ltd.) was used to collect 15-mL samples every 3.8 cm (1.5 in.) in the 3 m (10 ft) long screened interval. This device consists of a string of PVC cylindrical cells whose endcaps are 0.2- μ m cellulose acetate 25 mm (1 in.)-diameter filters (Fig. 2). The cells are separated by circular viton spacers that are cut to precisely fit the well in which the device is used. Finally, a Geoprobe was used to collect aqueous samples less than 0.5 m (1.6 ft) to all of the monitoring wells. Samples were acquired using a peristaltic pump. Phar-med 5 mm (0.2 in.) i.d., 8 mm (0.3 in.) o.d. tubing was used on the pump head [about 30 cm (12 in.) long] to minimize absorption and gas transfer, and polyethylene tubing was used for the remainder of the sample line. Stainless-steel, v-wire screens, 30 cm (12

in.) long, 2.5 cm (1 in.) o.d. were used to collect water at the desired sampling depths.

Sampling and Analysis Procedures

The low-flow sampling procedures described in previous research publications (Puls et al. 1992; Puls and Powell 1992) were generally followed when using the Grundfos Redi-Flo2 electric submersible pump to collect samples. Water levels were measured and recorded prior to purging and were monitored continuously during purging to evaluate drawdown in the wells. Flow rates were adjusted to about 0.4 L/min to minimize drawdown to less than 0.1 m (4 in.). A flow-through cell with data logger (Hydrolab H20) was used to continuously monitor pH, temperature, dissolved oxygen, oxidation-reduction potential, and specific conductance. Turbidity was measured about every 3–5 min using a Hach model 2100P turbidimeter. All instruments were precalibrated daily according to manufacturers recommendations. Equilibration of water quality parameters (WQPs) was defined as three successive readings within $\pm 10\%$ for DO and turbidity, $\pm 3\%$ for specific conductance, ± 10 mV for Eh, and ± 0.1 for pH. Temperature was recorded but not used for stabilization assessment. Samples were collected after turbidity equilibrated during purging and this was less than 5 NTUs for this method. The well was sampled twice using this method. The first time, the pump intake was set at approximately 0.6 m (2 ft) above the bottom of the well and the second time it was located 0.6 m (2 ft

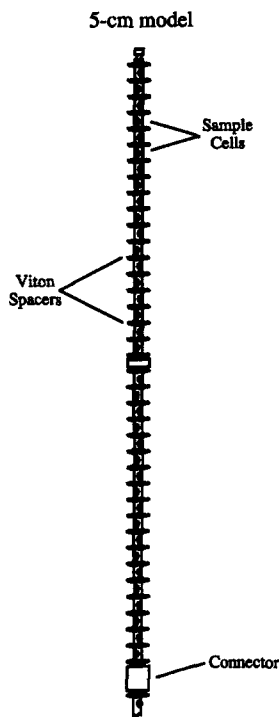


FIG. 2. DMLS Sampler for 5-cm-diameter Wells. Illustration is for 1.5-m-Long Unit that Was Connected to Another 1.5-m Unit for Insertion into 3-m-Long Well Screen (well 45) in this Study

below the top of the well in the 3 m (10 ft) long screen. Sampling at the two different locations within the screen was conducted to determine if pump location relative to plume location affected contaminant concentrations.

When the bailer was used, three well volumes (volume of water standing in the casing and screened interval) were used as a standard purge volume criteria. The same WQPs were measured, but only after each well volume was collected, and these values were not used for evaluation of well purging sufficiency. These samples had substantially greater turbidity (>100 NTUs) than those collected using low-flow purging and sampling techniques.

The DMLS cells (with 0.2- μ m filters as endcaps) were filled with distilled deionized water, loaded into the PVC rod and inserted into the screened interval of the well. Formation water enters the cells due to osmotic forces. If laminar flow is reestablished between the formation, sandpack (when present), and well, then samples recovered in the individual cells should be representative of the adjoining formation water (Ronen et al. 1987). The sampler was left in place 32 days before it was withdrawn for sample collection. The device was pulled out of the well and water samples were transferred directly from the cells to sample bottles. There were 72 total cells (Fig. 2) used in the DMLS sampler. The cells were spaced 3.8 cm (1.5 in.) apart within the central PVC rod. These cells were numbered 1 to 72. Odd-numbered cells were designated as metal-analysis samples (chromium and other metals) and the even-numbered cells were designated as anion-analysis samples (chloride, sulfate).

Geoprobe samples were collected using 30 cm (12 in.) screens on 60 cm (24 in.) intervals across the screened interval of the sampled well. Samples were collected using low-flow sampling techniques following initial development for each desired sampling depth.

The sampling sequence was as follows.

1. Removal of DMLS (morning of day one)
2. Well bailed (afternoon of day one), pump installed following bailing

3. Well pumped (lower level, morning of day three), pump relocated in upper level
4. Well pumped (upper level, afternoon of day four)
5. Geoprobe (day six)

Samples collected for metal analysis were filtered using Gelman high-capacity in-line 0.45- μ m filters, except for the DMLS samples, which were automatically filtered in place as water passed through the filter endcaps under natural gradient flow. Samples for metals analysis were immediately acidified with ultrapure nitric acid to less than pH 2 and analyzed using a Jarrell-Ash Model 975 inductively coupled plasma. Hydraulic conductivity estimates for the sampled zone of the aquifer were acquired using a cone penetrometer equipped with a ground-water sampler (hydrocone) using pore-pressure dissipation techniques (Hydrologic Inc., Subsurface Technologies). Anion analyses were performed using ion chromatography (Dionex DX-300).

RESULTS AND ANALYSIS

The DMLS and Geoprobe sampling approaches produced chromium concentration profiles that were surprisingly similar (Fig. 3), given the differences associated with the two sampling approaches. These differences included the following.

1. For the Geoprobe, samples are collected from a particular point in the aquifer under suction lift pressures, and at a particular point in time; thus, the samples are re-

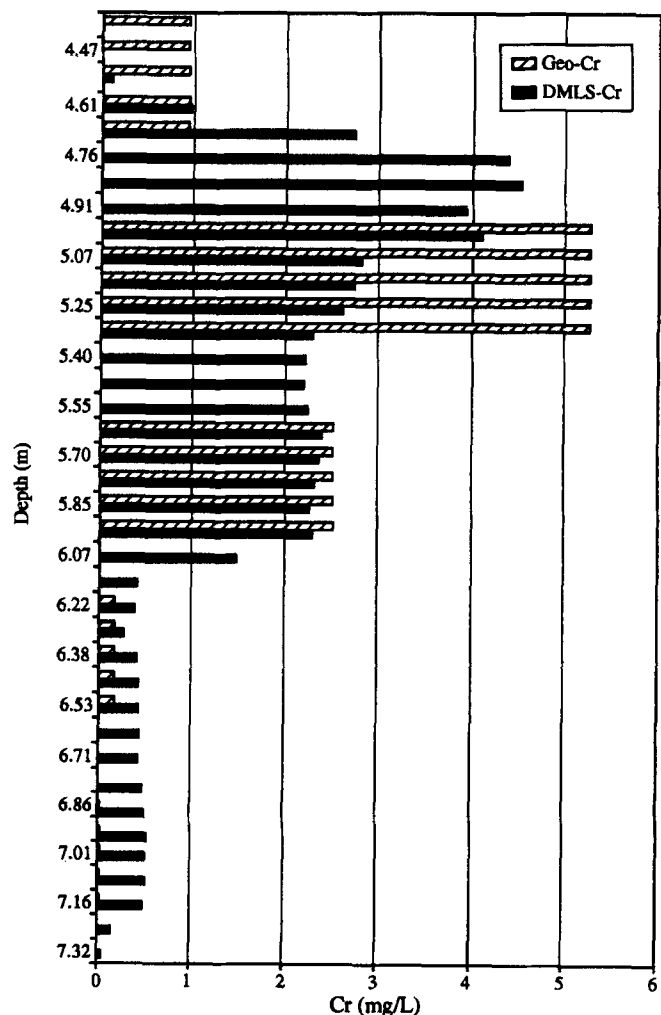


FIG. 3. Chromium Concentration Data for Geoprobe and DMLS Samples for Well 45

flective of the plume location on the day the samples are collected. For the DMLS sampler, the samples represent water from a particular level within the screen, whereby the water moves into the sampling device under natural gradient flow and the samples are collected over a longer time interval and in a passive manner; thus, the samples reflect any changes that may occur with respect to plume location changes over a much longer time interval.

- The Geoprobe samples are pumped to the surface and filtered under positive pressure through a large-capacity 0.45- μm filter, whereas the DMLS samples are passively

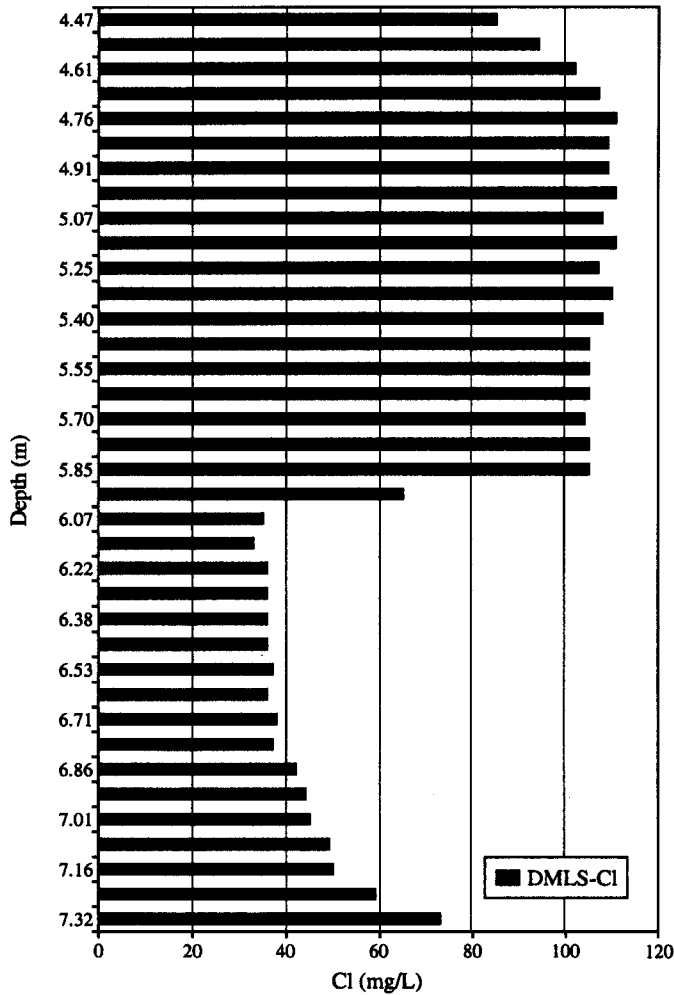


FIG. 4. Chloride Concentration Data from DMLS Samples for Well 45

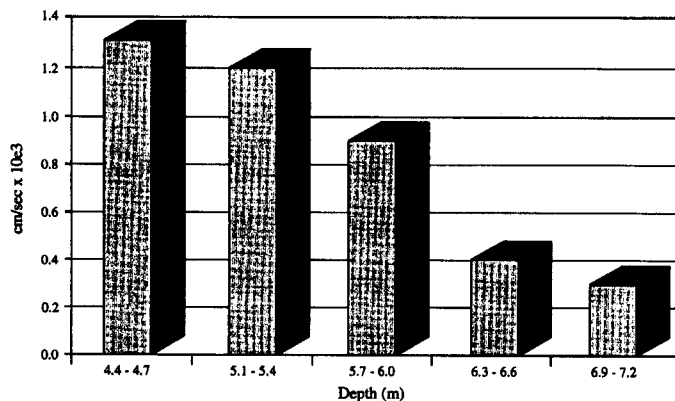


FIG. 5. Hydraulic Conductivity Estimations for Well 45 Using Cone Penetrometer Equipped with Hydrocone and Pore Pressure Dissipation Techniques

filtered through a 0.2- μm , membrane filter. If the elements analyzed are particle-reactive (i.e., adsorb strongly to solid phases in the system), then differences could be expected due to filter pore size differences and the presence of suspended colloidal particles in the flow system. Small differences in the two sets of data can be attributed to the preceding differences together with the fact that the Geoprobe samples represent a 30-cm vertical zone, whereas the DMLS cells only cover a 3.8 cm (1.5 in.) vertical zone.

The chloride profile from the DMLS is shown in Fig. 4. There is a clear difference in chloride concentration between 4.5 and 6.0 m below ground surface. This layer of high chloride concentration coincides with the highest chromium concentrations (Fig. 3) and the greatest hydraulic conductivity estimates for this part of the aquifer (Fig. 5). There is generally decreasing permeability with depth. Permeabilities above 6.0 m (20 ft) are two to three times greater than those below this depth.

The data for samples collected using the three-well volume purging method with bailer and the low-flow purging method with a submersible pump are shown in Fig. 6. Because of the manner in which the bailed samples are collected these data represent an average over the entire screened interval and significantly underestimate the average contaminant mass compared to the other three sampling approaches. These comparisons are listed in Table 1. The data represent the average of

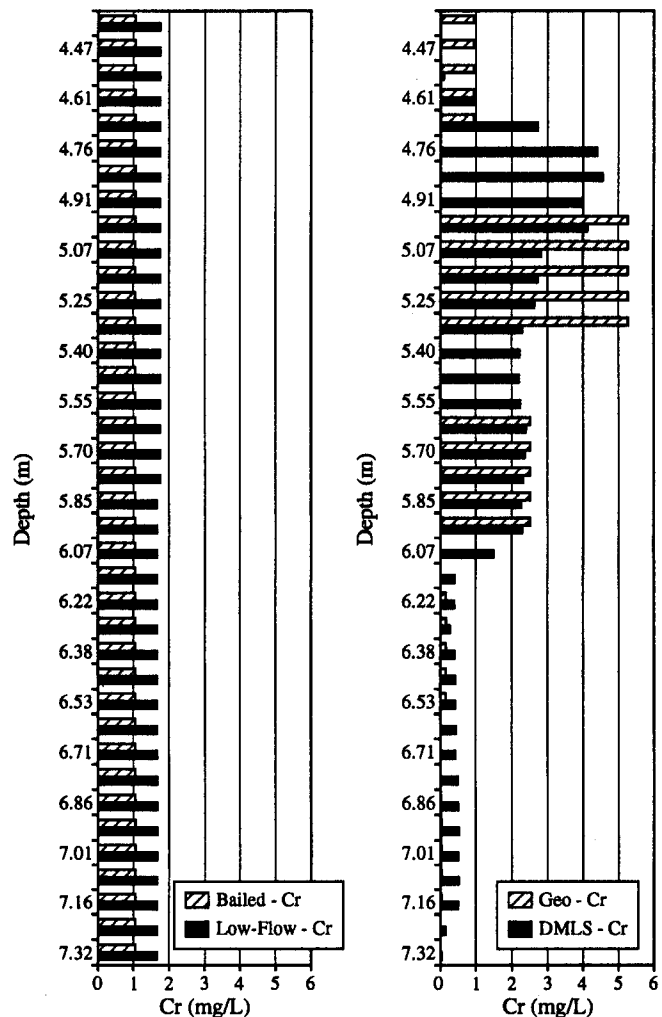


FIG. 6. Chromium Data for Samples Collected Using DMLS, Low-Flow, and Bailed Sampling Approaches for Well 45 in September 1995

TABLE 1. Average Values for Chromium over Sampled Interval Using Four Different Sampling Devices and Approaches

Device* (1)	DMLS (2)	Geoprobe (3)	Lo-flo (4)	Bailed (5)
Cr (mg/L)	1.69	1.86	1.76	1.05

*DMLS = DMLS multilayer sampler, Geo = Geoprobe with peristaltic pump, Low-Flo = low-flow purging with Grundfos Redi-Flo2, Bailed = three-well volume purged with Teflon bailer.

data collected for the same screened interval length for the four different approaches. With the exception of the bailed data, all are within 10%. One reason the bailed samples are significantly lower may be due to filtration artifacts. The bailed samples had turbidity in excess of 100 NTUs. High particulate loading in the water samples may contribute to filter clogging that decreases the effective filter pore size. Because of the need to transfer the water sample to another container to accomplish filtration, there is extended exposure to atmospheric gases (e.g., oxygen). Oxidation of ferrous iron may contribute to the formation of additional solids in solution in addition to those artificially entrained by the bailing action. These solids may serve as adsorption sites for chromium, resulting in lower aqueous concentrations in the water samples. It is always preferable to minimize disturbance within the well during sampling and to minimize sample handling at the surface; the bailer method does neither.

The low-flow purging method with a low-speed submersible pump produced screen-interval-averaged chromium concentrations comparable to the DMLS and Geoprobe methods; however, there is still considerable smearing or averaging of the concentration profile within the sampled zone (Fig. 6), with a chromium concentration of 1.76 mg/L near the top of the screened interval and 1.67 mg/L near the bottom. Even pumping at 0.4 L/min caused considerable mixing within the screened interval. Some of this mixing may be attributed to pump insertion, as this well did not have a "permanently dedicated" pump installed.

CONCLUSIONS

The DMLS sampler provided discrete-interval data from a conventional monitoring well that was generally consistent with adjacent formation water acquired with the Geoprobe sampling approach. The water within the screened interval of

the well appears to be representative of the adjacent formation water. The availability of chromium concentration profile data makes it possible to accurately assess contaminant distribution and mass. Knowledge of the accurate location of contaminant mass together with hydraulic conductivity variations in vertical layers may be extremely important in optimizing remedial designs. The DMLS sampler could be used to provide accurate, discrete-level data for early detection of contaminant leakage or breakthrough from a containment or subsurface treatment system without the need to purge and dispose of large quantities of water at the surface and discriminate sources of leakage over very short intervals. While the DMLS sampler was useful in providing representative samples for metals and anions in the present study, additional research is needed to confirm its usefulness and reliability in measuring volatile organics, radionuclides, and other contaminants.

ACKNOWLEDGMENTS

Although the research described in this paper has been funded wholly or in part by the U.S. Environmental Protection Agency, it has not been subjected to the Agency's peer and administrative review and, therefore, may not necessarily reflect the views of the Agency and no official endorsement may be inferred. Mention of trade names or commercial products does not constitute endorsement or recommendation for use.

APPENDIX. REFERENCES

- Puls, R. W., and Barcelona, M. J. (1996). "Low-flow (minimal draw-down) ground water sampling procedures." *Ground Water Issue, EPA/540/S-95/504*, U.S. Enviro. Protection Agency.
- Puls, R. W., and Paul, C. J. (1995). "Low-flow purging and sampling of ground-water monitoring wells with dedicated systems." *Ground Water Monitoring and Remediation*, 15(1), 116-123.
- Puls, R. W., and Powell, R. M. (1992). "Acquisition of representative ground water quality samples for metals." *Ground Water Monitoring Rev.*, 12(3), 167-176.
- Puls, R. W., Clark, D. A., Bledsoe, B., Powell, R. M., and Paul, C. J. (1992). "Metals in ground water: sampling artifacts and reproducibility." *Haz. Waste and Haz. Mat.*, 9(2).
- Puls, R. W., Paul, C. J., Clark, D., and Vardy, J. (1994a). "Transport and transformation of hexavalent chromium through soils and into ground water." *J. Soil Contamination*, 3(2), 203-224.
- Puls, R. W., Paul, C. J., Clark, D., Vardy, J., and Carlson, C. (1994b). "Characterization of chromium-contaminated soils using field-portable X-ray fluorescence." *Ground Water Monitoring and Remediation*, 14(3), 111-115.
- Ronen, D., Margaritz, M., and Levy, I. (1987). "An in situ multilevel sampler for preventive monitoring and study of hydrochemical profiles in aquifers." *Ground Water Monitoring Rev.*, 7, 69-74.