Low-Flow Purging and Sampling of Ground Water Monitoring Wells with Dedicated Systems

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Abstract

A field study was conducted to assess purging requirements for dedicated sampling systems in conventional monitoring wells and for pumps encased in short screens and buried within a shallow sandy aquifer. Low-flow purging methods were used, and wells were purged until water quality indicator parameters (dissolved oxygen, specific conductance, turbidity) and contaminant concentrations (chromate, trichloroethylene, dichloroethylene) reached equilibrium. Eight wells, varying in depth from 4.6 to 15.2 m below ground surface, were studied. The data show that purge volumes were independent of well depth or casing volumes. Contaminant concentrations equilibrated with less than 7.5 L of purge volume in all wells. Initial contaminant concentration values were generally within 20 percent of final values. Water quality parameters equilibrated in less than 10 L in all wells and were conservative measures for indicating the presence of adjacent formation water. Water quality parameters equilibrated faster in dedicated sampling systems than in portable systems and initial turbidity levels were lower.

Introduction

It is generally accepted that monitoring wells must be purged to access formation water and obtain representative ground water quality samples. However, there has been considerable controversy and research concerning the best way to accomplish this. Historically, anywhere from three to five casing volumes have been removed prior to sample collection to evacuate the standing water and access the adjacent formation water. This has most often been done with a bailer or a high-speed submersible pump positioned near the top of the water column. Generally, fast removal of the (nonrepresentative) casing water has been considered beneficial in terms of reducing sampling time and minimizing costs. This has been especially true for deep, large diameter, long-screened (>1.5 m) wells.

Excessive stress or disturbance on the formation from bailers and high-speed pumps may entrain immobile particles that have adsorbed contaminants. Large concentrations of suspended particles in samples collected for analysis are problematic because contaminants present on these particles may or may not be mobile in the aquifer (McCarthy and Zachara 1989). Since we are usually only interested in the mobile fraction, this compromises the integrity of the samples. In the past, highly turbid samples were not viewed as a problem where regulatory entities permit filtration of water quality samples; however, many states and some programs of the U.S. Environmental Protection

Agency (EPA) now prohibit filtration for metals analyses due to potential sampling artifacts created during the purging process which lead to the production of turbid samples or artifacts generated during the filtration process itself (U.S. EPA 1992). Also, recent research has indicated the potential for colloidal-size (generally less than about 1 μm) particles to be mobile in ground water (Gschwend and Reynolds 1987; Buddemeier and Hunt 1988; Penrose et al. 1990) and facilitate the transport of contaminants (Enfield and Bengtsson 1988; Puls and Powell 1992a). While little or no effects from turbidity have been observed for volatile organic samples (Paul and Puls 1994), large concentration differences between filtered and unfiltered samples have been observed for metals (Puls and Barcelona 1989; Puls et al. 1992; Pohlman et al. 1994).

Another problem with past sampling practices is that the manner in which wells are purged and sampled is often inconsistent with the use of the resultant data. The volume of water purged, the rate at which it is withdrawn, and the location of the sampling device intake all contribute to how well the sample represents the adjacent water bearing zone. The evacuation of three well volumes in a 200-foot-deep well with a 20-foot screen whose water table is 20 feet below ground surface removes a large volume of water and averages a large volume of the aquifer in the water sample. Since many contaminant plumes are narrow or thin, mixing with clean portions of the aquifer can provide misleading data concerning contaminant presence and concentration gradients. If the sampling objective is a large, volume-averaged concentration of the water bearing zone, then a consistent large sample volume, removed in a consistent manner, will generally provide reproducible values. However, if the sampling objective is accurate spatial and temporal plume delineation, then alternative methods of sample collection may be necessary.

To address many of these problems and concerns, an alternative purging strategy for use with conventionally installed monitoring wells has been proposed using pumps that permit much lower flow rates (<1 L/min), providing minimal drawdown and placement within the screened interval of the monitoring well (Puls and Powell 1992b; Puls 1994; Barcelona et al. 1994). This approach purges and samples much smaller aquifer volumes and has been referred to as low-flow purging, micropurging, or millipurging. These terms refer to the water velocity at the intake of the sampling device and the resulting induced formation water velocity, not the average discharge at the surface. The overall objective of low-flow purging is a more "passive" approach to sample collection: the ideal is to match the sampling device intake velocity with the natural ground water flow velocity and thereby to reduce sample disturbance. This is most easily evaluated by monitoring drawdown in the well and adjusting flow rate to minimize that drawdown. Research has shown that purging at lower rates with various types of pumps (peristaltics, low-speed submersibles, and bladder pumps) does produce low turbidity and high-quality samples (Puls and Barce-

lona 1989; Puls et al. 1992; Backhus et al. 1993; Barcelona et al. 1994).

A perceived problem with low-flow purging is prolonged purging time. With low-flow purging, the purge volume or purge duration is evaluated through continuous monitoring of water quality parameters such as dissolved oxygen, specific conductance, oxidation-reduction (redox) potential, and turbidity. Upon equilibration of these parameters, it is assumed that formation water is being accessed and sampling can be initiated. Our research with portable sampling equipment has shown that the volume of water required to achieve parameter equilibration using low-flow techniques is generally less than two casing volumes and in deeper wells only a fraction of a casing volume (Puls and Powell 1992b; Puls 1994). This suggests that the purge volume is independent of well size or casing volume. Studies using a downhole camera during purging and sampling suggest that the installation of the sampling devices themselves causes the most disturbance to the sampling point and increases the purge time (Puls and Powell 1992b; Kearl et al. 1992).

Powell and Puls (1993) clearly demonstrated the chemical differences that exist between the stagnant casing water and the underlying screened interval water in monitoring wells. They also demonstrated the ability to sample the screened interval water and the adjacent formation water while excluding the overlying nonrepresentative stagnant casing water using low-flow sampling techniques with dedicated sampling systems. If low-flow purging techniques in combination with the use of dedicated sampling systems can further minimize turbidity, by-pass the stagnant casing water, and access formation water almost immediately, then the time required to obtain samples and the volume of water brought to the surface for site assessments and routine monitoring could be drastically reduced. This study evaluated the use of low-flow purging methods in dedicated sampling installations in conventional monitoring wells. Equilibration of water quality parameters, together with time series sampling of contaminants and water chemistry, was used to evaluate the purge volume required to access formation water.

Study Site

The field site is located at the U.S. Coast Guard (USCG) Support Center near Elizabeth City, North Carolina, about 100 km south of Norfolk, Virginia, 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. The topography of the site is essentially flat and 2 to 3 m above sea level. The river has a width of approximately 3.2 km along the USCG base's northern boundary and a depth of 3 to 4 m. Hangar 79 contains a chrome plating shop that had been in use for more than 30 years; it discharged acidic chromium wastes through a hole in the concrete floor. These wastes (chromic acid, sulfuric acid, and chlorinated solvents) infiltrated the soils and

the underlying aquifer immediately below the shop's foundation.

The site geology consists of typical Atlantic coastal plain sediments, characterized by complex and variable sequences of surficial sands, silts, and clays. In the vicinity of the plating shop, the surface soils are silty clays. These overlie a thin sandy clay layer at about 1.5 m, which is above a sequence of sands and silty fine sands. In some locations, a dense gray clay layer substitutes for the sandy clay layer at 1.5 m. Fine to medium sands dominate from 4 to 20 m. A dense gray clay unit (Yorktown Confining Unit) persists at a depth of 20 m. The ground water table fluctuates from 1.7 to 2.5 m below ground surface.

Materials and Methods

Monitoring Wells and Sampling Pumps

Eight monitoring wells at the Elizabeth City site were studied. All but two were 5-cm (2-inch) diameter Schedule 40 PVC wells with 0.25-mm (0.010-inch) slotted screens. The wells were installed in June 1991 by hollow-stem auger drilling techniques. Filter packs (using sieve #6 to 10 washed sand) were installed to 0.7 m above the top of the screen. A 0.5-m-thick bentonite seal was installed above the filter pack followed by grout to the surface. All wells were surface completions in a concrete parking lot. Other characteristics of the sampled wells used in the study are listed in Table 1. The wells ranged in depth from 4.6 to 15.2 m below ground surface and screen length ranged from 0.5 to 3 m. System volume (Table 1) refers to the volume of water in the tubing and the water quality parameter measurement device (QED Purge Saver®). Well volume (Table 1) refers to the water in the monitoring well itself which varied somewhat over time due to fluctuations in the water table level. Two of the wells (MW 25, MW 31) were actually buried pumps and were therefore

installed without casing. For these two wells, a permanently dedicated PVC bladder pump (QED) and a permanently dedicated variable-speed submersible pump (Redi-Flo2®, MP1: Grundfos) were encased in 0.25-mm slotted screens which were 0.9 m and 0.5 m long, respectively. These were sealed and 0.63-cm (0.25-inch) Teflon®-lined polyethylene tubing was connected from the pumps to the surface for sampling. For the caseless Grundfos, a sandpack was used inside the screen, whereas for the caseless QED pump, glass beads were used as the packing or filter material. Pump intakes were located within the packed screens. These units were lowered inside 7-cm-diameter hollow-stem augers to the desired depth and the formation was allowed to collapse in around the units. These systems are referred to as permanently dedicated because they cannot be removed for servicing. The same types of pumps and tubing were also used in the traditional monitoring wells.

Following installation, all wells (including the buried pump wells) were immediately developed using pumping rates between 5 and 10 L/min. The pumping device (Redi-Flo2) was continually raised and lowered throughout the screened interval during development. Water was pumped until turbidity levels were less than five nephelometric turbidity units (NTUs). This was generally accomplished with less than 200 L of water pumped.

Purging and Sampling Procedures

The pumps (except for the buried pumps) were set with the pump intake at approximately mid-screen. Following installation (April 1992), the pumps remained in place throughout the study (April 1992 to June 1993). Data was first collected in August 1992, and then again in February, March, and June 1993. Water levels were measured (QED Sample Pro® [conductivity sensor and

Table 1 Well Data, Elizabeth City, North Carolina							
Well	Depth[1]	Screen[2]	Device[3]	WQPEV[4]	CCEV[5]	System Vol.[6]	Well Vol.[7]
2	4.6	1.5	CS	7.5	7.5	0.6	5.6
13 (7/92)	4.6	1.5	CS	7.0	4.5	0.6	5.6
13 (6/93)	4.6	1.5	CS	7.0	7.0	0.6	5.6
14	6.1	1.5	BL	10.0	4.5	0.9	8.7
15	4.6	1.5	BL	6.0	5.5	0.8	5.6
16	4.6	1.5	CS	4.0	3.5	0.8	5.6
22	15.2	3.1	CS	7.5	2.5	1.3	27.2
23	7.1	0.9	BLp	7.5	3.5	0.8	0.5
31	4.9	0.5	CSp	6.5	3.5	0.6	0.3

[1]Depth = well depth in m
[2]Screen = screen length in m.
[3]CS = low-speed centrifugal submersible pump, BL = bladder pump, CSp = permanently buried low-speed centrifugal submersible pump, BLp = permanently buried bladder pump.
[4]WQPEV = water quality parameter equilibration volume in L.
[5]CCEV = contaminant concentration equilibration volume in L.
[6]System volume = volume (L) of tubing and flow-through cell.
[7]Well volume = volume (L) of water in well casing and well screen.

tape])) and recorded prior to and during purging to evaluate drawdown, which was minimized to less than 0.1 m. Pump flow rates ranged from 0.22 to 0.55 L/min. In all cases prior experience at the site indicated that these flow rates would produce <0.1 m of drawdown; however, this was checked approximately every three minutes during purging and slight flow rate adjustments were made when necessary. The sampling procedures described in previous research (Puls et al. 1992; Puls and Powell 1992b) were generally followed, except all purge water was collected in sequential 500-mL increments for analysis of volatile organics (trichloroethylene [TCE], cis-dichloroethylene [DCE], and vinyl chloride), major cations and metals, anions, and chromium. Samples referred to as initial were the first 500 mL of water pumped to the surface, including any standing water in the pump and tubing. Samples referred to as final were the first 500-mL increment after equilibration of water quality parameters. A flow-through cell with data logger (QED Purge Saver) was used to continuously monitor pH, temperature, dissolved oxygen (D.O.), and specific conductance (S.C.). Turbidity was measured separately using a Hach Ratio/XR® turbidimeter. Purging and continuous sampling continued beyond equilibration of water quality indicator parameters to a maximum of 21 L of removed water. Equilibration was defined as three successive readings, three minutes apart, within ±10 percent for D.O. and turbidity, ±3 percent for specific conductance, and ±0.05 for pH. Equipment accuracies are ±2 percent for turbidity and D.O., 3 percent for specific conductance, and ±0.02 for pH. Criteria were based on equipment specifications as well as historical equilibration plots generated for all wells (>30) at the site. Temperature was recorded but not used for equilibration evaluation. Temperatures monitored at the surface are affected to some extent by the difference between ambient air and ground water temperatures and thus vary at different times of the year. Other factors such as tubing length and thickness and extent of exposure to sunlight will also affect temperature readings at the surface. Temperature is a relatively insensitive parameter with respect to discriminating between formation, screened, and stagnant water.

Sample Preservation and Laboratory Analyses

Metal samples, including chromium, were analyzed with a Jarrell-Ash Model 975 inductively coupled plasma (ICP). Samples were also analyzed for $Cr(VI)$ using a colorimetric method that uses diphenylcarbazide as a complexing agent (Skougstad et al. 1979). There was less than 5 percent difference between the ICP and colorimetric method, indicating nearly all the chromium was present in the ground water as $Cr(VI)$. Metal samples were immediately acidified following collection to pH <2 using ultrapure concentrated nitric acid. Anion analyses were performed using ion chromatography (Dionex DX-300). Volatile organics were collected directly into 45-mL glass vials and stored and transported on ice for laboratory analysis. The samples were purged on a Tekmar® sample concentrator and the analytes trapped on a VOCARB 4000 (Supelco) trap. Anal-
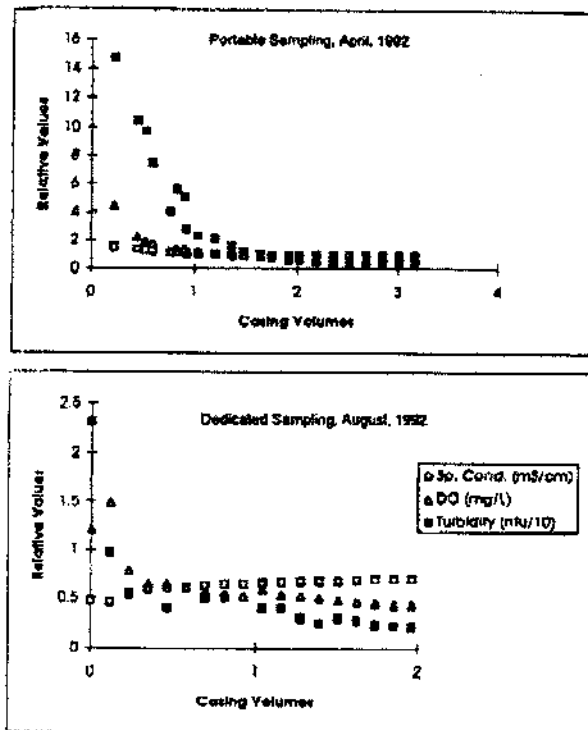

Figure 1. Comparison of water quality parameter equilibration for MW 16, Elizabeth City, North Carolina. The April 1992 data was obtained with portable sampling equipment, whereas the August 1992 data was obtained with dedicated sampling equipment. The same pump (variable-speed submersible) and flow rate (0.225 L/min) were used in both cases.

ysis was done with a Hewlett-Packard 5890 gas chromatograph with a flame ionization detector and a 30-m capillary column. The compounds were cryofocused onto the column using liquid nitrogen. Detection limits for TCE, c DCE, and vinyl chloride were 1 μg/L, and 10 μg/L for chromium.

Results and Discussion

Purge volume results in terms of water quality parameter (WQP) equilibration and contaminant concentration (CC) equilibration are listed in Table 1. These volumes represent the maximum volume pumped following equilibration of all WQPs and CCs. The CC equilibration criteria were three successive samples (500-mL increments) within ±10 percent. WQP equilibration was determined as referenced earlier. WQP and CC equilibration volumes were independent of well depth or well volume. WQP equilibration volumes ranged from 4 to 10 L, while CC equilibration volumes ranged from 2.5 to 7 L. The two dedicated permanent wells (MW 23, 31) had some of the smallest CC equilibration volumes, as might be expected due to the minimal stagnant well water above the pump (0.64 to 0.81 L in buried pump tubing). Among the conventional monitoring wells studied, the smallest CC equilibration volume was for the deepest well (MW 22, 13.2 m), while the largest CC equilibration volume was for the shallowest well (MW 2, 4.6 m).

Figure 1 shows the comparison of WQP equilibration for MW 16 for two different sampling events (April
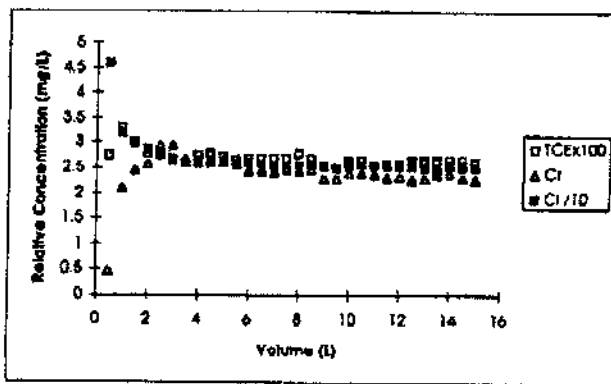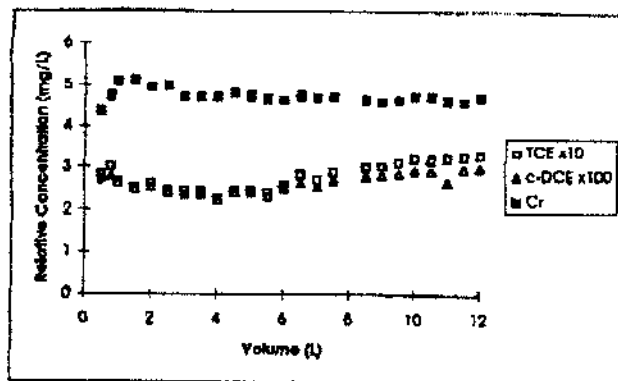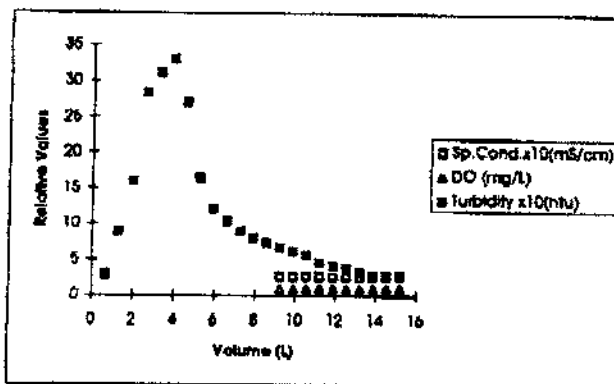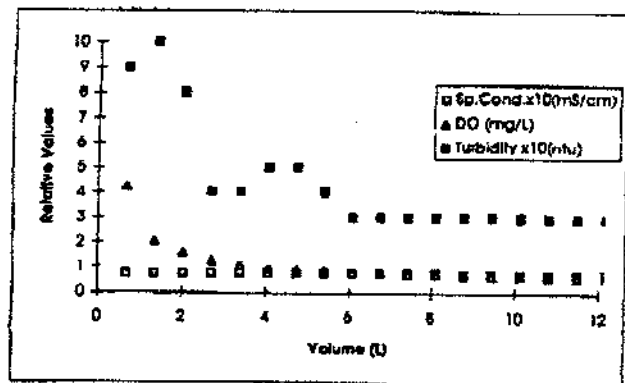
Figure 2. Equilibration of water quality parameters and contaminant concentrations using time series sampling of MW 2, Elizabeth City, North Carolina (variable-speed submersible pump).

Figure 3. Equilibration of water quality parameters and contaminant concentrations using time series sampling for MW 14, Elizabeth City, North Carolina (bladder pump).

1992, August 1992). The April data were collected with portable equipment, while the August data were collected with dedicated equipment; the same equipment was used both times. All WQPs started out at lower levels and equilibrated faster using the dedicated sampling system. WQP equilibration volumes were 0.7 and 1.8 well volumes (4 and 10 L) for the dedicated and portable sampling systems, respectively. Equilibrated chromium and TCE concentrations were within 10 percent and some of this variation might be attributed to temporal variability.

Equilibration of WQPs and CCs are shown in Figures 2 through 4 for conventional monitoring wells of different depths. MW 2 (Figure 2) is 4.6 m deep with a 1.5 m screen and was sampled with the variable-speed submersible pump. Equilibration of both WQPs and CCs occurred within 7.5 L, although initial and final CCs varied by less than 10 percent. MW 14 (Figure 3) is 6.1 deep with a 1.5 m screen and was sampled with a bladder pump. Once again, differences between initial and final CCs were less than 10 percent. Problems with the flow cell prevented the acquisition of WQP data at the initial stages of purging. CC levels equilibrated within 4.5 L. For the deepest well, MW 22 (15.2 m deep, 3 m screen), equilibration of CCs occurred within 2.5 L (Figure 4), and there was less than 8 percent difference in initial and final CCs. The equilibration of WQPs for all three wells followed the same general pattern with exponentially decreasing turbidity and dissolved oxygen
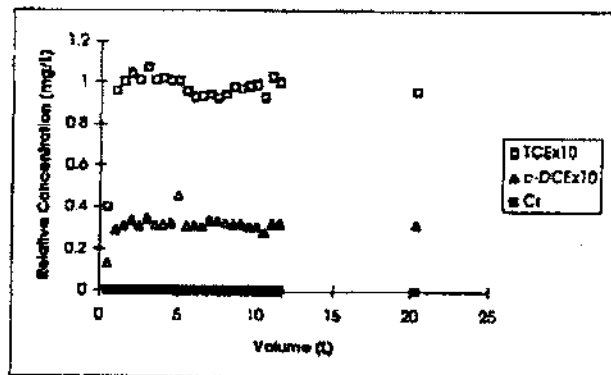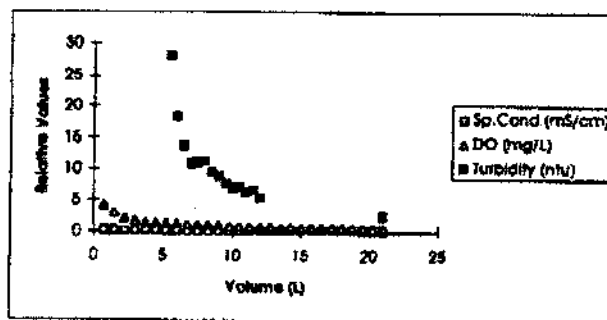

Figure 4. Equilibration of water quality parameters and contaminant concentrations using time series sampling for MW 22, Elizabeth City, North Carolina (variable-speed submersible pump).
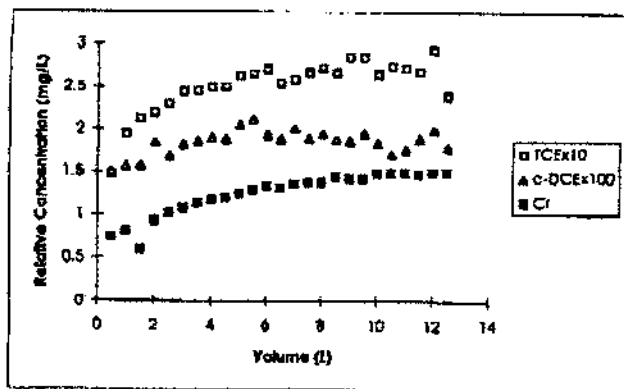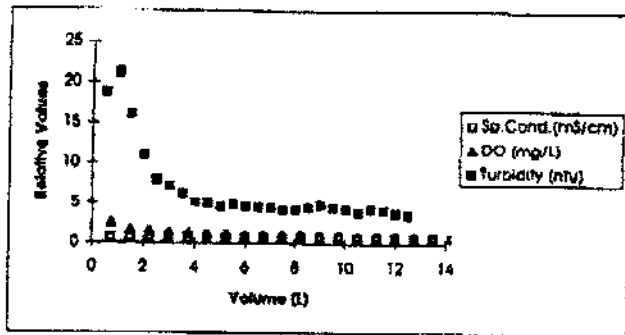
Figure 5. Equilibration of water quality parameters and contaminant concentrations using time series sampling for MW 23, Elizabeth City, North Carolina (buried bladder pump).
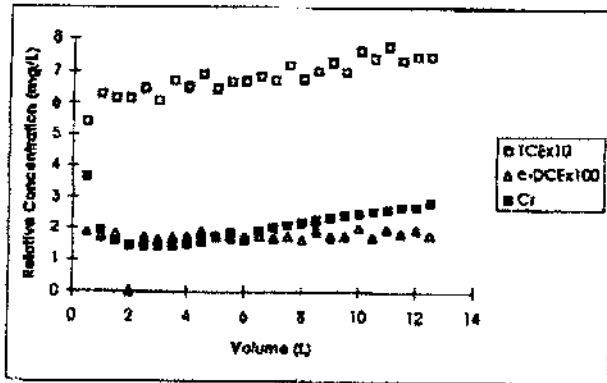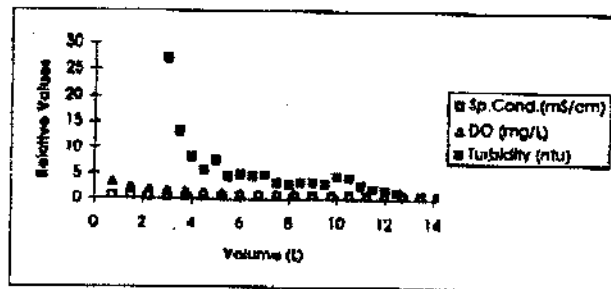
Figure 6. Equilibration of water quality parameters and contaminant concentrations using time series sampling for MW 31, Elizabeth City, North Carolina (buried variable-speed submersible pump).

and relatively flat or constant specific conductance values.

Data for the buried wells with permanently dedicated pumps are shown in Figures 5 and 6. Equilibration of WQPs was essentially the same as for the conventional monitoring wells. There was essentially no difference in required time to equilibrate for the two different pumps in these permanently buried installations. Contaminant levels in MW 31 tended to steadily increase with time, perhaps due to a natural concentration gradient that exists in the immediate vicinity of the pump intake. This was also true for MW 23, although to a lesser extent. This phenomenon has been previously described by Reilly and Gibs (1993). These pumps have continued to successfully operate after more than two years since burial.

Figures 7 and 8 show the equilibration behavior for both the WQPs and CCs in MW 13 using the same dedicated sampling setup, but sampled on two dates, in July 1992 and June 1993. The final equilibrated concentration values for chromium and TCE were within 5 and 10 percent, respectively, on the different dates. These were extremely close considering potential temporal variability differences. Interestingly, there was a substantial difference observed between the initial TCE concentrations for the two dates. In June 1993 the initial TCE concentration was 0.35 mg/L compared with 0.70 in July 1992, while the values at equilibrium were roughly equivalent (Table 2). The D.O. profile was somewhat higher for June compared with July during the first 3 L of sample collection, indicating more gas
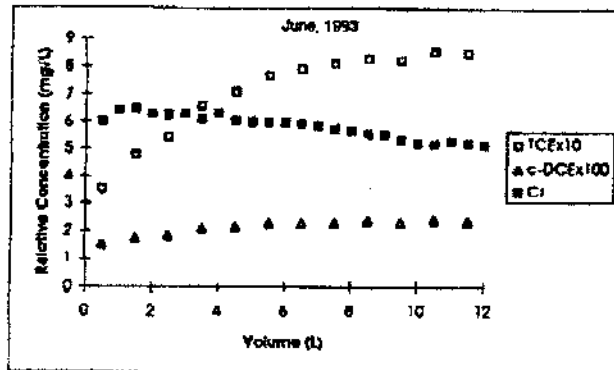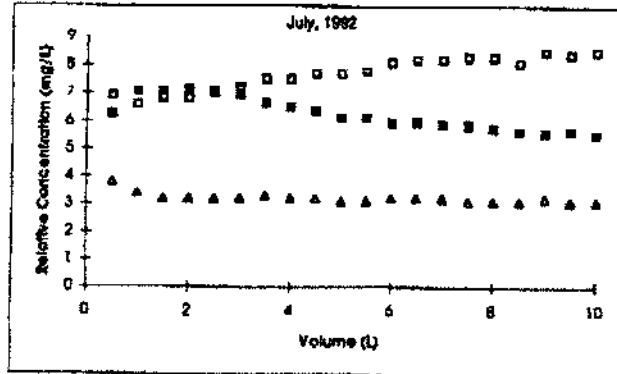

Figure 7. Equilibration of contaminant concentrations using time series sampling for MW 13, Elizabeth City, North Carolina, on two dates (upper, July 1992; lower, June 1993) using the same pump (variable-speed submersible pump).
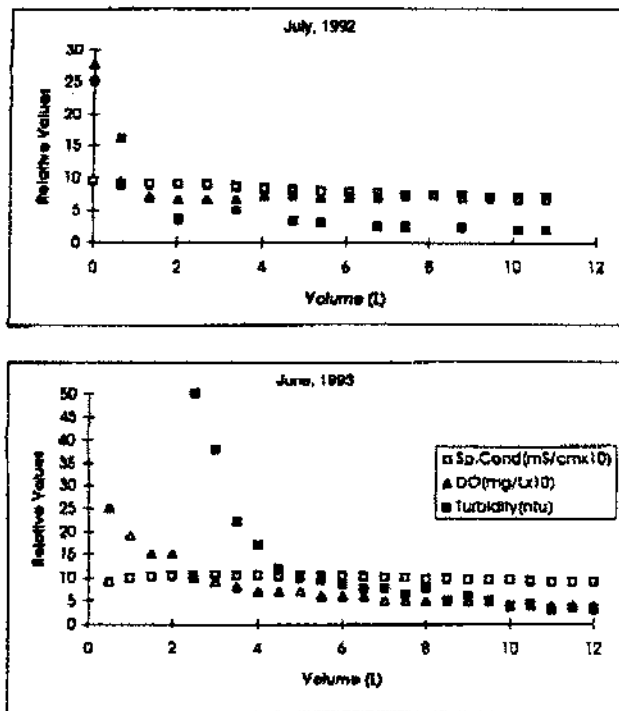
Figure 8. Equilibration of water quality parameters for MW 13, Elizabeth City, North Carolina, on two dates (upper, July 1992; lower, June 1993) using the same pump (variable-speed submersible).

transfer across the air-water interface within the water column of the well. This inverse correlation between D.O. and TCE suggests the potential for some volatilization losses of TCE within the well. This is a shallow well (4.6 m) and the water column above the screened interval is only 1.3 m. The turbidity profiles are also substantially different with much higher turbidity during the first 4 L in June. The DCE concentrations are also uniformly lower for June compared to July. Fluctuations in the water table elevation over time may have caused changes in concentration and water quality parameters in the immediate vicinity of the well screen in this shallow well.

A comparison of all three target contaminant levels following an initial three-volume sampling system flush (Table 1; tubing and flow-through cell) and those values obtained after final equilibration of WQPs is shown in Table 2. Initial vs. final contaminant concentration differences ranged from less than 1 to as much as 50 percent, while 77 percent of the initial values were within 20 percent of the final equilibrated concentrations. These results are similar to those obtained by Powell and Puls (1993) using passive sampling techniques and comparing water chemistry of the screened interval water to adjacent formation water chemistry. These results indicate that in many cases the water moving through the screened interval may indeed represent the adjacent formation water; however, well purging and a means of detecting formation water (equilibrated water quality parameters) are still required to ensure sample quality.

Conclusions

Purging requirements were independent of well depth or casing volumes and contaminant concentration levels equilibrated after less than 7.5 L of water was removed in all wells. Following the purging of three sampling system volumes, initial concentration values were generally within 20 percent of final values, indicating that the water in the screened interval was very similar to the adjacent formation water. Water quality indicators equilibrated in less than 10 L in all wells and in all instances were conservative measures for the time to access adjacent formation water. Equilibrated turbidity values were very low (<5 NTUs) in all wells, and initial values were lower in dedicated sampling systems than with portable or temporarily installed equipment.

An alternative conceptual model considers the evacuation of only a portion of the screened interval volume rather than the entire casing volume. Depending upon well depth and the analytes of interest, bladder or low-speed submersible pumps may be used with the intakes positioned within the screened interval at the desired sampling depth. Significant reductions in purge

Table 2
Contaminant Concentration Equilibration Data[1]

Well	Cr-initial	Cr-final	TCE-initial	TCE-final	c-DCE-initial	c-DCE-final
2	5.05	4.80	0.260	0.288	0.251	0.270
13 (7/92)	7.13	5.88	0.703	0.811	0.032	0.032
13 (6/93)	6.46	5.83	0.54	0.79	0.018	0.023
14	2.83	2.41	0.028	0.026	—	—
15	0.90	1.01	0.075	0.127	0.010	0.011
16	1.62	1.42	11.80	11.00	0.625	0.454
22	0.0	0.0	0.101	0.093	0.031	0.033
23	1.01	1.37	0.229	0.266	0.017	0.020
31	1.44	1.87	0.613	0.684	0.017	0.017

[1]Initial concentrations are given in mg/L after the initial system flush (i.e., three system volumes (tubing + flow cell), or 2 to 4 L; see Table 1) and final contaminant concentrations following the equilibration of WQPs.

volume and waste disposal requirements may be obtained using dedicated systems, and thorough economic analyses may show this to be a cost-effective alternative for routinely sampled monitoring wells. Proper well construction and well development become increasingly important where these strategies are used. A detailed understanding of the hydrologic and geologic variability of the system as well as the specific goals and objectives of the ground water monitoring program is essential in establishing sampling points and designing the overall sampling program.

Acknowledgments

Disclaimer

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