Ground Water Monitoring&Remediation

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Ground Water Purging and Sampling Methods: History vs. Hysteria

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Introduction

We practice in a field that has seen remarkable progress in approaches to site characterization, monitoring, field instrumentation, and remedial technologies over the past 25 years. Cleanup approaches have been developed and successfully applied to sites that are contaminated with chemical constituents that very few people even knew existed until the mid-90s. It is an exciting field to work in because we have rapidly come a long way. At the same time, it is frustrating that issues that had largely been solved 10 or 20 years ago are still news to some practitioners.

It has been over 10 years since the low-flow ground water purging and sampling method was initially reported in the literature. The method grew from the recognition that well purging was necessary to collect representative samples, bailers could not achieve well purging, and high-flow purging produced large volumes of potentially contaminated water in need of transport and treatment. Low flow has been widely adopted, leading to documented, consistent performance in diverse hydrogeologic settings for virtually all analytes of interest.

"Problem(s) solved?" Not quite! Despite the fact that the method has been shown to be useful in situations different from those in which the method was initially applied, there are regulators who refuse to approve its use or arbitrarily specify values for flow rate, drawdown, etc.

In this review, we draw on the history of ground water purging and sampling methods to underscore the need to bring recognition of what works to assist in the development of regulatory guidance. In addition, we offer an illustrative example of low-flow purging and sampling performance under high- and low drawdown conditions.

Historical Development of Purging and Sampling Methods

The early development of ground water sampling guidance grew out of drinking water supply programs that emphasized the use of production wells (Todd et al. 1976). When monitoring programs under the Resource Conservation and Recovery Act (RCRA) and the Comprehensive Environmental Response, Compensation and Liability Act (CERCLA) shifted toward contaminant source detection and assessment, the design and construction of monitoring wells called for the development of sampling procedures that would access water from the hydrostratigraphic zones where release and transport may occur. These procedures had to be applicable to smaller diameter, intermittently pumped wells in a wide variety of yield conditions. It was also important that the procedures yield water samples representative of formation conditions for the analysis of water quality parameters (e.g., pH, conductance, dissolved oxygen [D.O.]), metallic elements, and organic micropollutants (e.g., volatile organic solvents and fuels) often at the detection limits for these parameters.

Gibb et al. (1981) conducted some of the initial research toward this end, demonstrating the sensitivity of sampling results to well-purging rate, volume, and the degree of disturbance of in-well conditions. A consistent finding in their work was that the values of water quality parameters often stabilized within purging less than six well volumes. These observations were adopted by Federal regulatory programs as recommendations for sampling monitoring wells (Federal Register 1984; U.S. EPA 1988). These recommendations stipulated three to five well-volume purging and specific design characteristics for monitoring well construction, which emphasized screen placement in the most likely impacted or protected aquifer zones. By the early 1980s, the importance of well location and construction, as well as quality-assured sample collection, was well documented (Scalf et al. 1981; Gillham et al. 1983; Barcelona et al. 1983, 1985). However, sampling practices differed widely, owing largely to the continued use of bailers (with regulatory approval) and the widespread application of a three-to-five well-volume purging rule rather than using these numbers as a guideline as actually intended by the original research work.

Inconsistent sampling practices have persisted, despite the fact that it has been well established that it is not

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possible to properly purge a monitoring well with a bailer (Martin-Hayden et al. 1991; Robbins and Martin-Hayden 1991). At the same time, further neglect of the unique hydraulic characteristics of monitoring wells led to the use of high-rate pumping devices. Rapid removal of the purge volume entailed potential disturbance of sample quality (i.e., aeration), caused screen dewatering, and induced artifactual turbidity or drawing in water from areas above (or below) the screened interval. In addition, high–flow rate purging resulted in the production of large volumes of potentially contaminated water that required costly handling and treatment. It was further recognized that purging was necessary due to in-well water quality changes (Barcelona and Helfrich 1986). The need for more effective and documented sampling methods was driven by the more stringent sampling and analytical data quality objectives, which are placed on micropollutant compliance monitoring programs (Clark and Baxter 1989; Keely and Boateng 1987; Barcelona 1988).

It is clear from published work that monitoring water quality parameters (e.g., D.O., specific conductance, pH) during purging and the use of stabilization of these parameters as indicators of access to formation water could minimize well and sample disturbance as well as purge volume (Robin and Gillham 1987; Pionke and Urban 1987; Maltby and Unwin 1992; Powell and Puls 1993). In this context, the basic practice of low–flow rate purging and sampling was developed to enable more efficient, quality-assured ground water sample collection (Barcelona et al. 1994; Puls and Barcelona 1996). Briefly, the method involves pumping from the screened interval of a monitoring well while monitoring water quality indicator parameters in an in-line flow cell at flow rates low enough to minimize disturbance of both well hydraulics (e.g., mixing, excessive screen intake velocity, screen dewatering, and turbidity) and the quality of water samples. Although not necessarily a requirement for collecting high-quality samples (screen intake velocity is a better indicator of disturbance), minimizing the drawdown in a monitoring well had the added benefit of reducing the required purge volume (less stagnant water from above the screen would be mixed in with the purged water). Therefore, the originally envisioned advantages of the method were significant reductions in sample disturbance and purge volume as compared to high–flow rate purging or bailer methods.

Actual purging flow rates should be reduced to minimize turbulence in the well. The effective isolation of stagnant water in the wellbore (i.e., above the screen) and induced flow of formation water into the screened interval depend mainly on the response of the formation to low–flow rate pumping. For example, in low–hydraulic conductivity formations, the screen entrance velocities could be kept low despite significant drawdown as long as drawdown stabilized. In this case, sample quality could still be high, but purge volumes or times may be proportionally higher. In high–hydraulic conductivity formations, it is easier to adjust flow rate to minimize drawdown (or allow stabilization) and screen intake velocities to collect high-quality samples. The key issue here remains minimal drawdown during purging not an arbitrary level.

The low-flow method was principally developed from observations in short (~5-foot or ~1.5-m)–screened, ≤2-inch (5.0-cm)–diameter wells in relatively highly transmissive hydrogeologic settings where flow rates on the order of ~1 L/min could be sustained with minimal drawdown. In these situations, the objectives of collecting high-quality samples and minimizing purge volume could be achieved. This is not the only set of conditions, however, where low-flow sampling is applicable and cost effective. The actual flow rate and amount of drawdown that a particular monitoring well could sustain depends on its hydrogeologic setting and well construction characteristics. The performance characteristics (e.g., drawdown and required purge volume) and type of well (short screened and small diameter) illustrated in the development of the method are not the only ones that are acceptable or that can be expected. The successful application of the method to low-yield wells in less-permeable formations (Vandenburg and Varljen 2000; Puls et al. 1992; Powell and Puls 1993), as well as in larger-diameter, longer-screened wells (Shanklin et al. 1995), led to more widespread adoption of the method by practitioners. Other papers have demonstrated that low-flow methods have excelled with a number of devices as compared to other purging approaches (Heidlauf and Bartlett 1993; Pohlmann et al. 1990).

This otherwise “rosy” picture has been clouded in recent years by two major seeming anomalies. The first is the concept of the flow-through well, which constantly renews formation water across the screen and maintains in-well water quality as a result of natural flow regardless of aquifer properties, well design, construction, and performance characteristics. The flow-through well and the inherent assumptions have given rise to the promotion of no-purge sampling (American Petroleum Institute 2000) and chemically selective passive diffusion bag samplers (PDBS) (Vroblesky and Campbell 2001).

The second anomaly in hydrogeochemical monitoring presents itself in the draft development or promulgation of arbitrary regulatory guidance for the specific elements of an acceptable low-flow sampling protocol. Several states and U.S. EPA regions have suggested that low-flow sampling must be tested and proven at every location, while at the same time there is no requirement to demonstrate the efficacy of older approaches. In this well-meaning guidance, drawdown during pumping must be limited to a specific value, regardless of well performance. In addition, the perception exists that low-flow sampling may only be applied to short-screened wells, and that the pump position in a well is of major significance and must be researched at every location (e.g., Oregon-DEQ 2002; New Mexico Environmental Department, 2001), based on the suspicion that low-flow sampling might “miss” contaminants. Let us examine these two in detail.

The Flow-Through Well

A number of papers address whether or not there is sufficient natural gradient-driven flow through the screened interval of a monitoring well to provide “fresh” water (isolated from that stored in the well casing) and therefore minimize the need for purging prior to sampling

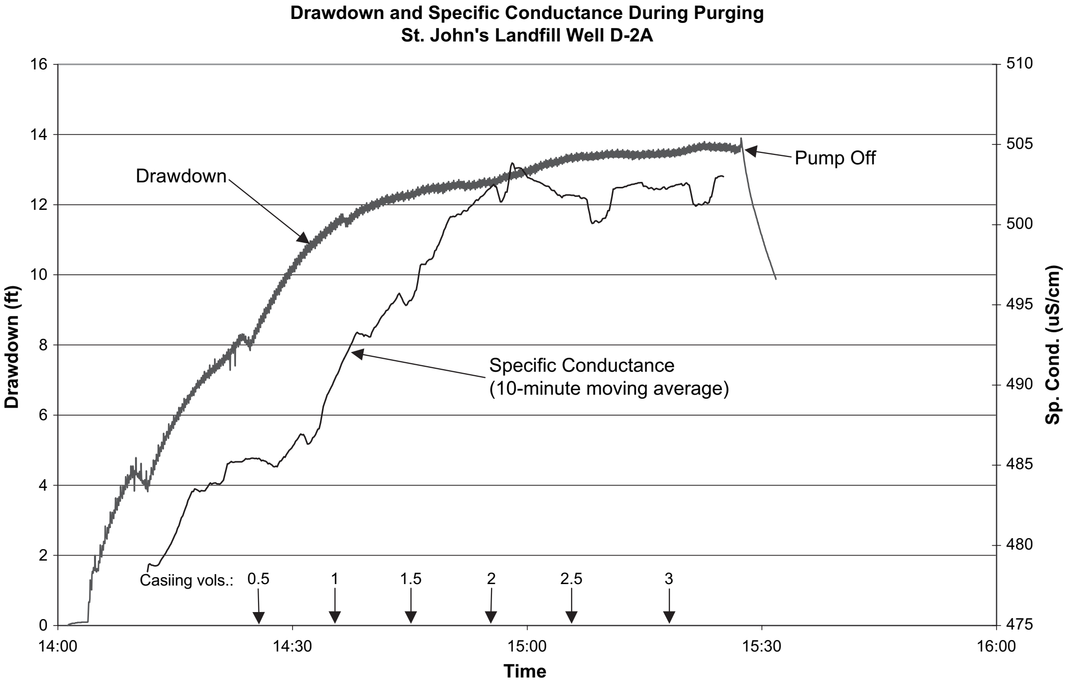

Figure 1. Drawdown and specific conductance during purging well D-2A.

Table 1
Purging Results for Well D-2A

	Number of Casing Volumes Purged Before Sampling						
Parameter	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**
1,4-DCB	0.001	0.00438	0.004525	0.004595	0.005085	0.004925	0.004095
As	0.139	0.1065	0.1045	0.105	0.109	0.106	0.108
Ba	0.5565	0.516	0.495	0.515	0.5275	0.526	0.5345
Cl	79.25	82.8	85.1	85.9	85.8	85.85	84.15
Clorobenz	0.00671	0.01165	0.0122	0.0123	0.01305	0.0128	0.01135
Cr	0.00885	0.0046	0.0038	0.00405	0.0049	0.0041	0.00425
Fe	27.6	23	21.9	22	21.6	20.7	20.8
Fe-D	21.35	21.85	20.6	19.85	19.6	19	19.65
Hardness	436	434.5	430	405.5	408	405.5	402.5
Mn-D	0.472	0.4415	0.408	0.382	0.365	0.361	0.367
N-NO_3	0.117	0.105	0.227	0.1855	0.2435	0.31	0.292
NH_3	67.05	81.4	88.3	85.9	90.8	90.8	88.3
Pb	0.04895	0.00665	0.00655	0.00815	0.0166	0.0085	0.0071
Sec-Butbenz	0.001	0.001	0.001	0.00115	0.001205	0.001185	0.001
SO_4	27	36.15	37	29.85	29.65	28.5	30.15
TSS	129	66	65	77.5	88.5	64.5	55.5
Zn	0.1635	0.0425	0.0481	0.0586	0.09225	0.0481	0.0471
Time	14:05	14:24	14:35	14:45	14:55	15:05	15:20
Temperature (°C)	22.44	20.24	20.67	20.67	20.92	21.13	21.4
pH	5.94	6.44	6.45	6.46	6.46	6.46	6.46
Conductance (μS/cm)	437	480	499	493	508	500	503
D.O. (mg/L)	3.9	0.1	0.09	0.08	0.08	0.08	0.08
Eh (mV)	389	172	170	160	164	164	166
Drawdown (feet)	0.66	8.1	11.28	12.31	12.62	13.15	13.57

Note: All results are in mg/L unless units are specified. Numbers reported are the average of two duplicate samples collected simultaneously. See attached analytical data package (Appendix A) for raw data that were used in producing the average figures shown. Differences in the number of significant digits among results for a given parameter are the result of averaging duplicate samples. The differences do not reflect different levels of analytical precision. Shading indicates parameter was not detected above the listed value, which represents the analytical method detection limit.

(Robin and Gillham 1987; Maltby and Urwin 1992; Powell and Puls 1993). The bulk of this work has been done on partially penetrating wells with submerged screens ~5 feet (1.5 m) long.

The evidence from the literature is that, under natural gradient conditions, flow through the screened interval is expected to occur in permeable formations (Kearl, et al. 1994), principally from the most permeable strata in the screened interval (Marsh and Lloyd 1980). In fact, Crisma et al. (2001) and Elci et al. (2001) have definitely shown through borehole flow measurements and model simulations that flow through the screened interval will vary under ambient and pumping conditions. The permeability of the screened formation and adequate well design (i.e., sand pack, screen, and development) play controlling roles. Their work further confirms the value of discrete, short-screened well completions in clusters to replace long-screened wells for monitoring purposes.

It has long been recognized that, under pumping conditions, the nature and extent of flow into the screened interval depends on the degree of vertical heterogeneity of the formation as well as the relative permeability of the sand pack/screen and aquifer (Cohen and Rabold 1988; Gibs et al. 1993; Reilly and LeBlanc 1998). Given the range of hydrogeologic and chemical conditions in which monitoring wells have been placed, it would be unwise to presume for any given well that flow is occuring through the screened interval in an unpumped state without proof. Even if flow occurs through the screen, it has been demonstrated that mixing with stagnant water in the wellbore (Maltby

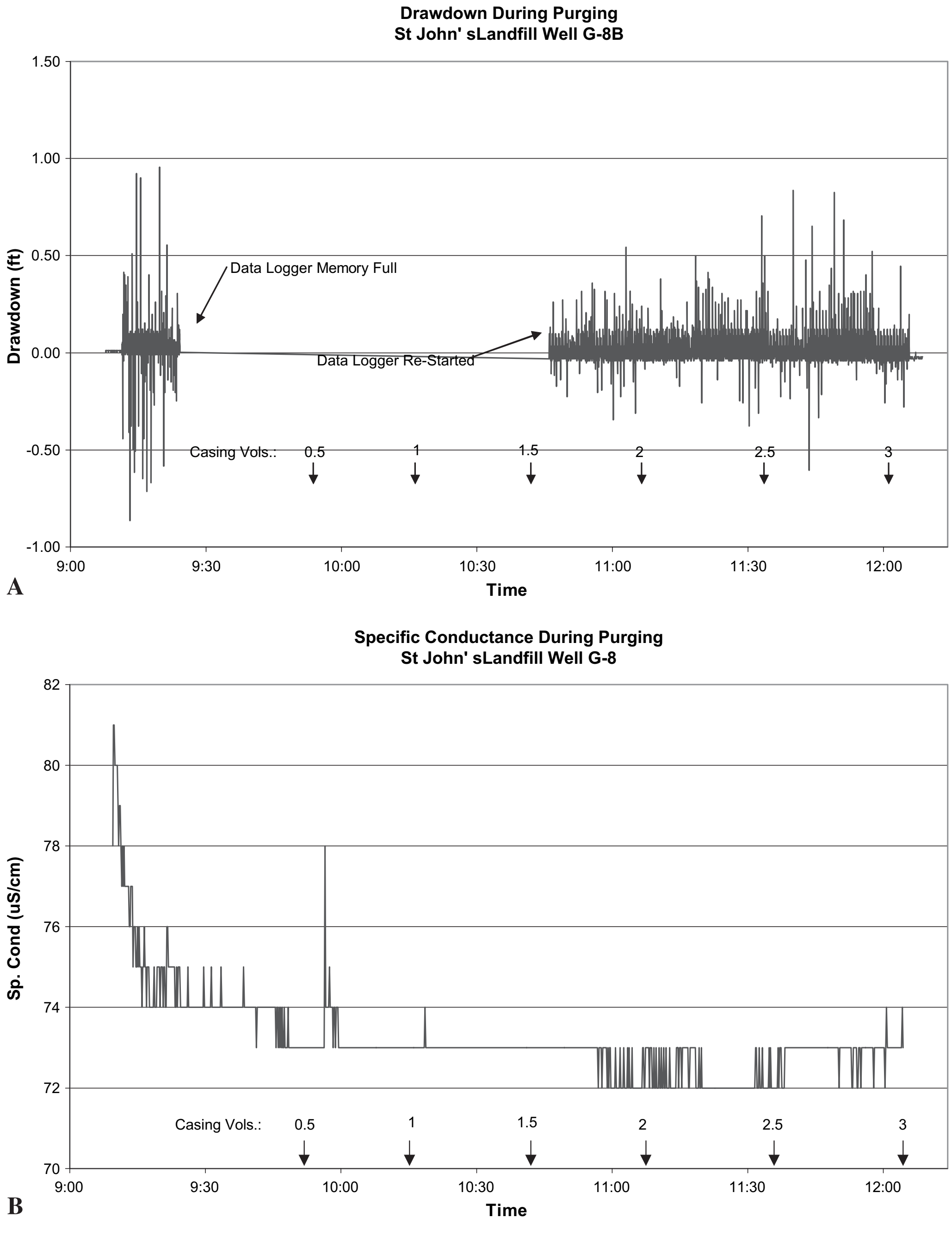

Figure 2. (A) Drawdown during purging St. John's landfill G-8B. (B) Specific conductance during purging St. John's landfill well G-8B.

and Urwin 1992; Robin and Gillham 1987) and in-well chemical/physical disturbance would alter water quality from that existing in the aquifer (Barcelona and Helfrich 1986).

It has also been recognized recently that PDBS performance is, in large measure, controlled by the hydrophobicity of organic compounds (i.e., log octanol-water partition coefficients) and ground water flow velocity (Booij et al. 2003). Therefore, the assumption of sustained horizontal flow through well screens should be scrutinized very carefully.

The foregoing discussion has focused on a rather ideal subset of well design, construction, and hydraulic performance where little drawdown is observed during pumping for sampling purposes. In practice, there are numerous monitoring wells in use that experience substantial drawdown during sampling, and the inference is drawn that low-flow purging and sampling methods are inapplicable. Remember, however, that the low-flow method recommendations allow for minimal or stable drawdown during sampling though appreciable drawdown may occur during purging. An illustrative example of low-flow sampling performance under minimal and significant, but stable, drawdown follows.

Low-Flow Purging and Sampling under Low- and High-Drawdown Conditions

Probably the most common monitoring wells in use are those at landfill sites, which frequently are completed in low-permeability formations, that minimize contaminant migration. Let us examine the results of a controlled sampling experiment with the low-flow purging method in high- and low-permeability formations at a landfill site in the Pacific Northwest. The wells D-2A and D-8b were completed in low- and high-permeability hydrostratigraphic zones, respectively, at a municipal solid waste landfill.

In this case study (Vandenberg and Varljen 2000), two landfill monitoring wells completed in high- and low-permeability formations were purged by standard, low flow, and no purge (initial pumped sample prior to purging) using a bladder pump with a flow cell. Both the standard (three well volume) and low-flow purging and sampling were done at <0.5 L/min flow rate. D.O., pH, conductance, temperature, and redox potential were monitored in a flow cell, while drawdown was measured via an in situ pressure transducer. In addition major cations, selected anions, Fe II and NH_3, volatile organic compounds (VOCs), and trace element samples were collected during the purging operation. Duplicate samples were taken at half well volume intervals to three well volumes.

Figure 1 shows drawdown and specific conductance as a function of volume pumped for well D-2A. In this case, drawdown as well as specific conductance, redox potential, and D.O. stabilized at approximately two well volumes pumped. Of particular significance is that the fact that drawdown stabilized and the indicator parameters (and contaminants of concern as shown in subsequent figures) stabilized concurrently. Also, inspection of the data for well D-2A (Table 1) reveals that the initial zero-volume sample was significantly higher in D.O., redox potential, total iron, and zinc than the low-flow (two volume) purged

Table 2
Purging Results for Well G-8B

	Number of Casing Volumes Purged Before Sampling						
Parameter	**0**	**0.5**	**1**	**1.5**	**2**	**2.5**	**3**
1,1,1-TCE	0.001	0.00124	0.00128	0.001215	0.00122	0.00126	0.001245
1,1-DCE	0.001355	0.00159	0.001665	0.00163	0.00166	0.001685	0.00165
ALK-T	63	58	64	59	61	62	60
As	0.0039	0.00395	0.00385	0.00395	0.0041	0.004	0.00365
Ba	0.01215	0.0111	0.0107	0.0109	0.0106	0.0105	0.0105
c-1,2-DCEe	0.00483	0.00862	0.008805	0.00873	0.009135	0.00923	0.009065
Cl	3.685	3.87	3.84	3.875	3.88	3.875	3.92
Cr	0.002	0.0021	0.00205	0.0021	0.00205	0.00235	0.00225
Hardness	77.85	81.75	75.95	78.15	79.2	79.75	80.4
N-NO_3	2.17	2.755	2.755	2.775	2.81	2.83	2.84
SO_4	16.4	17.4	17.3	17.3	17.4	17.45	17.5
Tetcloethe	0.001	0.002385	0.002355	0.002225	0.002235	0.002095	0.002145
Triclethen	0.001	0.001555	0.001575	0.00156	0.001625	0.00158	0.00149
Time	9:05	9:50	10:15	10:40	11:10	11:40	12:05
Temperature (°C)	13.18	11.76	11.83	11.84	11.91	11.88	11.89
pH	6.16	5.7	6.18	6.17	6.16	6.2	6.19
Conductance (μS/cm)	78	73	73	73	72	73	73
D.O. (mg/L)	6.15	6.12	6.15	6.2	6.22	6.2	6.23
Eh (mV)	521	482	414	409	409	402	400
Drawdown (feet)	0	0	0	0	0	0	0

Note: All results are in mg/L unless units are specified. Numbers reported are the average of two duplicate samples collected simultaneously. Differences in the number of significant digits among results for a given parameter are the result of averaging duplicate samples. The differences do not reflect different levels of analytical precision. Shading indicates parameter was not detected above the listed value, which represents the analytical method detection limit.

or three volume samples, indicating that a no-purge sample at this location would not be representative. These observations are in agreement with previous observations of in-well changes in water chemistry (Barcelona and Helfrich 1986).

Figure 2A and 2B show the drawdown and specific conductance, respectively, during pumping for well D-8b. This well, completed in a more-permeable zone, experienced negligible drawdown (note the change in drawdown units), and indicator parameter stabilization occurred at approximately one-half well volume. In this situation, the differences between zero-volume, low-flow purge (half-volume), and the three-volume sample were negligible for most of the chemical parameters measured in the field and the lab (Table 2).

Figures 3A and B and 4A and B show the results of dissolved arsenic (As), 1,4-dichlorobenzene (1,4-DCB), and 1,1-dichloroethylene (1,1-DCE), and conductance determinations, respectively, on water samples as a function of purge volume for the two wells at this landfill site. The trace As and VOC results agree with those noted for the aforementioned chemical parameters in that the well finished in a more-permeable setting stabilized more rapidly than did the values in the well completed in the less-permeable zone. At concentration levels near practical detection limits, the purging behavior of these wells is clear. Even in

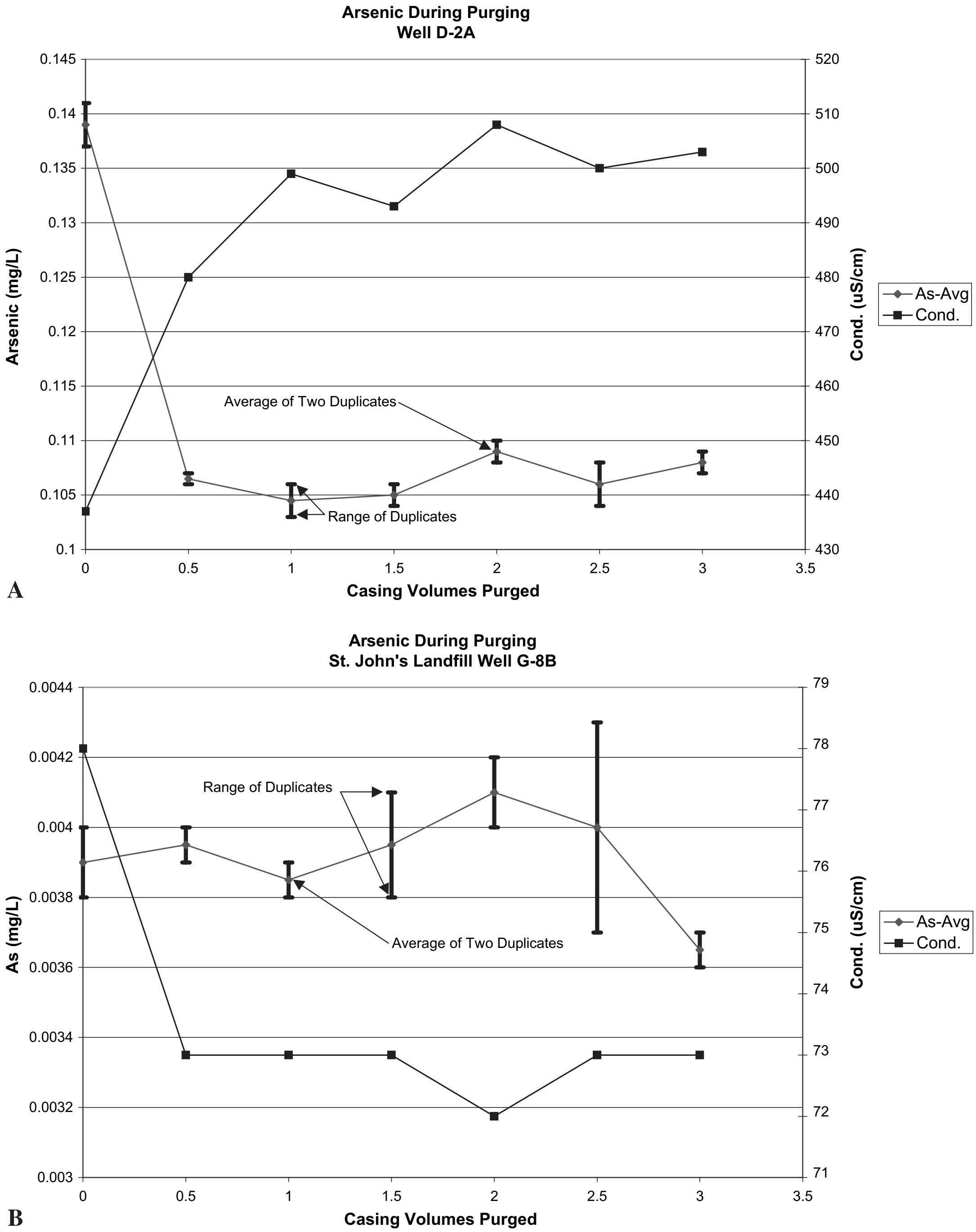

Figure 3. (A) As during purging well D-2A. (B) As during purging well G-8B.

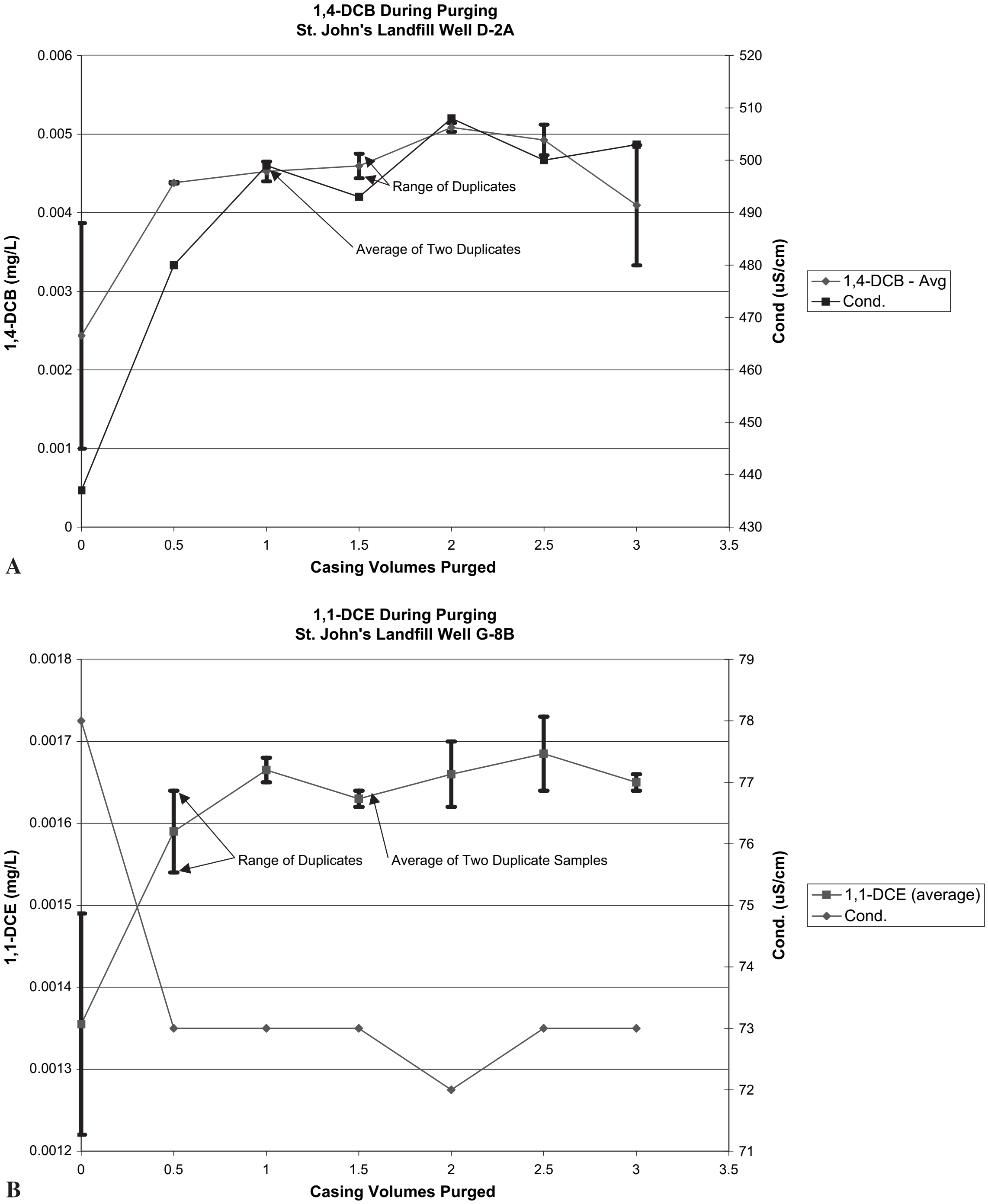

Figure 4. (A) 1,4-DCB during purging St. John's landfill well D-2A. (B) 1,1-DCE during purging St. John's landfill well G-8B.

the low-permeability well where drawdown was significant, collecting samples after indicator parameters (and drawdown) had stabilized yielded representative results. It is demonstrated that there would be little benefit in continuing purging out to three or more well volumes. We point out these observations as illustrative of the value of low-flow purging and indicator parameter measurement to establish a protocol for sampling in diverse monitoring situations. Concentrations of chemical constituents in specific situations may differ in magnitude, but the method serves to document well performance, and the fact that though drawdown may occur, it is not the degree of drawdown, but stabilization, that matters in collection of representative samples.

Conclusions

In summary, the available literature and results of the field trail underscore the need to evaluate monitoring well hydraulic performance and a protocol to measure indicator parameters. Low-flow purging has been shown to be applicable to a range of hydrogeologic settings. It presents an opportunity to document purging and sampling efforts and establish reliable, rather than arbitrary, sampling protocols.

In a related paper (Varljen et al. 2005), the effect of pumping rate, pump placement, and screen-length effects on purging behavior have been evaluated to encourage practitioners to adopt more reliable sampling protocols that are in tune with existing subsurface conditions.

We hope that the results of this work will also encourage the use of low-flow sampling and encourage regulatory agencies to incorporate flexibility in guidelines for monitoring network operation for a range of hydrogeologic settings and chemical constituents of interest.

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Editor's Note: The use of brand names in peer-reviewed papers is for identification purposes only and does not constitute endorsement by the authors, their employers, or the National Ground Water Association.

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