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EVALUATION OF SAMPLING AND FIELD-FILTRATION METHODS FOR THE ANALYSIS OF TRACE METALS IN GROUND WATER

by

Karl F. Pohlmann
Gary A. Icopini
Richard D. McArthur
Water Resources Center
Desert Research Institute
Las Vegas, Nevada 89119

Charlita G. Rosal
Analytical Sciences Division
Environmental Monitoring Systems Laboratory
Las Vegas, NV 89193–3478

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Project Officer

Charlita G. Rosal
Analytical Sciences Division
Environmental Monitoring Systems Laboratory
Las Vegas, NV 89193–3478

This study was conducted in cooperation with
Water Resources Center
Desert Research Institute
Las Vegas, NV 89119

ENVIRONMENTAL MONITORING SYSTEMS LABORATORY
OFFICE OF RESEARCH AND DEVELOPMENT
U.S. ENVIRONMENTAL PROTECTION AGENCY
LAS VEGAS, NEVADA 89193–3478

NOTICE

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ABSTRACT

Selected ground-water sampling and filtering methods were evaluated to determine their effects on field parameters and trace metal concentrations in samples collected under several types of field conditions. The study focused on sampling in conventional standpipe monitoring wells under conditions where traditional approaches to sampling may produce turbid samples, which often leads to the decision to filter suspended particles from the sample before laboratory chemical analysis. However, filtration may also remove colloidal particles that are known to be mobile under certain ground-water conditions and may be important to the transport of hydrophobic organic contaminants and trace metals. The specific sampling and filtration variables investigated in this study were (1) filtration with 0.45-μm pore size filters or 5.0-μm pore size filters versus no filtration; (2) sampling device, specifically bladder pump, submersible-centrifugal pump, and bailer; and (3) sampling pump discharge rate during purging and sample collection using a "low" rate of 300 mL/min and a "moderate" rate of 1000 mL/min. Three field sites were visited: an active municipal solid waste landfill in Wisconsin, a closed solid waste landfill in Washington, and a site contaminated by industrial waste in Nevada. Three wells at the Wisconsin and Washington sites and two wells at the Nevada site were included in the evaluation. Filtration with 5.0-μm filters was conducted only at one well at each site.

Bailers caused more disturbance of the sampling zone than the three pumping methods as evidenced by measurements of field parameters and concentrations of particles, major ions, and trace metals. Bailers also produced higher concentrations of particles of the size range potentially important to colloidal transport of contaminants (e.g., between 0.001 and 10.0 μm). Little variation was observed in the analytical determinations between the pumps but some variation existed in the field indicator parameters, primarily temperature, dissolved oxygen, and turbidity. Under low–yield conditions, the moderate–rate pumps produced dissolved oxygen and turbidity levels that were greatly elevated over those produced by the low–rate pump. The effects of field filtration were most evident for the bailer, which often produced trace metal concentrations in unfiltered samples that were orders-of-magnitude higher than in 0.45-μm-filtered samples. The largest differences occurred at the most turbid wells and in samples containing the highest particle concentrations, apparently reflecting the entrainment of normally non-mobile particles and associated matrix metals in the bailed samples. Similar effects were observed in some samples collected by pumps from the most turbid wells, particularly the low yield well. For most pump sampling, however, differences in concentrations between 0.45–μm–filtered and unfiltered samples were not significant and particle concentrations were significantly lower than those produced by the bailer. Overall, trace metal concentrations in 0.45-μm-filtered samples were generally independent of sampling method, suggesting that these constituents were present as dissolved species and not associated with particles or were associated with particles smaller than 0.4 μm. At wells where 5.0-μm filtration was conducted, physical and hydrochemical conditions resulted in minimal differences between trace metal concentrations in the 5.0-μm-filtered, 0.45-μm-filtered, and unfiltered samples.

CONTENTS

FIGURES

TABLES

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SECTION 1

INTRODUCTION

The U.S. Environmental Protection Agency (U.S. EPA) is studying how sampling techniques impact contaminant concentrations in ground–water samples. This study was undertaken to investigate how concentrations of trace metals were affected by selected methods of sample collection and field filtration. The study focused on sampling in conventional standpipe monitoring wells under conditions where traditional approaches to sampling may produce turbid samples, as might occur when sampling a monitoring well with an intake located in a water-bearing zone containing significant amounts of fine-grained materials. Although proper choice and careful implementation of sampling methodology is always important for the acquisition of quality ground-water samples, conditions of high turbidity and corresponding high particle concentrations make this especially significant.

BACKGROUND

Historically, ground-water contaminants were considered to be partitioned between two phases, a mobile phase composed of dissolved (aqueous) solutes in water transported by natural ground-water flow and a solid phase composed of the matrix materials of the water-bearing zone. This solid phase included the immobile formation itself and particles derived from the formation that may have concentrated around monitoring wells as a result of disturbance during well drilling and construction (Gillham et al., 1983). These large particles, often 10 μm and larger and often referred to as "suspended solids" or sediments, are generally immobile under natural ground-water flow conditions (with the exception of karst systems) and are usually settled out by gravity because ground-water velocities are insufficient to entrain them (Yao et al., 1971). The action of purging and sampling a monitoring well may, however, provide sufficient energy to suspend large particles that have accumulated in the sampling zone and inside the well bore and incorporate the particles in ground-water samples. Particles composed of clay minerals, various metal oxides, and humic material, may adsorb metal ions to their surfaces due to their high cation-exchange capacities. This is especially true of clay minerals that may contain metals as part of their crystal structure (Drever, 1988). Inclusion of metals associated with these normally immobile particles may bias analytical determinations, leading to elevated, and if suspended particle concentrations are very high, improbable concentrations of mobile contaminants.

Investigations of contaminant metals in ground water have generally focused on dissolved species because they were considered more likely to be transported under natural hydraulic gradients through ground-water systems, and because inclusion of particles in samples might incorporate matrix metals leading to biased determinations of contaminant metals concentrations (U.S. EPA, 1986). As a result, ground-water samples are commonly filtered in the field to remove these suspended particles. Filtration has been considered particularly necessary under turbid conditions where high particle (sediment) loadings might lead to significant analytical bias through inclusion of large quantities of matrix metals in the analysis. Alternatively, the presence of particles in samples might also bias analytical determinations through removal of metal ions from solution during shipment and storage as a result of interactions with particle surfaces.

Unfortunately, indiscriminant use of field filtration ignores the presence of particles in ground water that may exist between the extremes of solutes and sediments. These particles, referred to as colloids, are generally considered to be in the size range of 0.001 to 5.0 μm (Mills et al., 1991). Like larger particles, colloids are commonly composed of clay minerals, metal oxides, and humic material, and therefore, present likely sites for sorption of hydrophobic organic and inorganic constituents (McCarthy and Zachara, 1989; Puls 1990). But like dissolved species, the small sizes of colloids facilitate their mobility in certain ground-water systems, and also provide them with high ratios of surface area to mass which increases their relative sorptive capabilities (McDowell-Boyer et al., 1986). Association with colloids has been shown to provide an important mechanism for transport of hydrophobic contaminants in ground waters including radionuclides (Champ et al., 1982; Buddemeier and Hunt, 1988: Penrose et al., 1990) and metals (Tillekeratne et al., 1986; Gschwend and Reynolds, 1987; Magaritz et al., 1990).

The demonstrated potential for contaminant transport in association with colloids has important implications for the practice of field filtration because the boundary between particulate and dissolved has been operationally defined at 0.45 µm (U.S. EPA, 1979). This boundary presumes that the component retained on a 0.45 µm filter represents suspended solids, while the component that passes through the filter represents dissolved metals. However, filtration of ground-water samples may remove an unknown fraction of metals important to transport and lead to erroneous conclusions about contaminant mass and extent (Puls and Barcelona, 1989). This is more likely where significant concentrations of metals are associated with mobile colloids larger than the filter pore size.

Field filtration has other significant drawbacks. For example, spatial variation of ambient physical and geochemical conditions in the ground-water zone may cause a related distribution of aqueous and solid species of metals. Because field filtration is designed to allow passage primarily of dissolved species, those species present as mobile solids larger than the filter pore size at a particular well location may be removed during filtration. Further, the act of collecting a ground-water sample may cause metals to change from one species or phase to another, which could allow filtration to affect the concentrations present in the sample. As an example, exposure of samples to oxygen during sampling may cause oxidation of dissolved ferrous iron (Fe^{2+}) to ferric iron (Fe^{3+}), producing a ferric hydroxide precipitate (Stumm and Morgan, 1981), which if removed during filtration, could bias iron determinations. Finally, factors associated with the filtration process itself, such as filter type, filter diameter, filtration method, and sample volume, have been shown to affect trace metal concentrations in filtered samples, leading to uncertainty in the results (Horowitz et al., 1992).

The issues of colloidally-transported metals and field filtration become even more important when sampling produces turbid samples. This may occur when bailers or submersible pumps operated at moderate or higher discharge rates (greater than 1000 mL/min) are used in wells completed in formations containing fine-grained sediments or in inadequately designed, constructed, or developed wells. These sampling methods may entrain sediments and normally immobile colloids, thereby introducing bias to the analyses (Puls et al., 1991; Backhus et al., 1993). Under these conditions, filtering the samples to remove suspended material may also remove colloids and the metals associated with them. Collecting pumped samples at flow rates that approach natural ground-water advective flow velocities may reduce entrainment of normally immobile species, thereby alleviating the need to filter samples. This approach to sampling has been advocated by several researchers with maximum suggested pumping rates of 100 to 300 mL/min (Ryan and Gschwend, 1990; Puls et al., 1990; Kearl et al., 1992; Backhus et al., 1993).

Collection of ground-water samples for analysis of metals concentrations is required under several U.S. environmental regulations, including CERCLA (Superfund), RCRA Subtitle C (Hazardous Waste), and RCRA Subtitle D (Solid Waste). As a result, the debate regarding filtration of ground-water metals samples impacts a wide range of sampling programs and a large number of sites, suggesting the need for further study into the issue.

OBJECTIVES

This study assessed, under several types of field conditions, the impacts of selected aspects of ground-water sampling on field determinations of unstable parameters and analytical determinations of trace metal chemistry. The study focused on selected sampling methods that are applicable in conventional monitoring wells for ground-water sampling at solid waste landfills and hazardous waste sites. Disturbance of samples and the sampling zone (well intake, filter pack, and formation adjacent to the monitoring well intake) by the sample collection method was considered a critical factor affecting the accuracy of field and laboratory determinations of ground-water hydrogeochemistry. In particular, the interdependence of chemical concentrations and particle content was of interest because the presence of particles, and possible removal of a fraction of particles by filtration, might affect concentrations of certain trace metals. Therefore, sampling methods that minimize disturbance of the sampling zone were compared to more widely–used methods that are known to agitate the sampling zone during purging and sampling.

For this study, the term "particles" refers to analytically-determined solid material larger than 0.03 µm and includes both mobile colloidal material and normally immobile sediment mobilized by the sampling process. In addition, the term "trace metals" refers to those metals and metalloids that are often included in sampling programs at solid waste landfills and hazardous waste sites. This study focused on arsenic (As), barium (Ba), cadmium (Cd), chromium (Cr), iron (Fe), lead (Pb), manganese (Mn), and nickel (Ni). In addition to being a result of contamination from a waste disposal site, trace metals such as these may originate from natural components of the formation matrix, or as a consequence of monitoring well drilling, construction, and sampling activities. To address the issue of ground–water transport of trace metals from a waste disposal site, artifacts resulting from these other factors must be minimized.

The specific objectives of the study were to provide a survey of the impacts of the following aspects of ground-water sampling:

1. Impacts of sample collection method on determinations of field parameters.
2. Impacts of filtration with 0.45-µm pore size filters or 5.0-µm pore size filters versus no filtration on trace metal concentrations.
3. Impacts of sampling device, specifically bailer, bladder pump, submersible-centrifugal pump at a "low" discharge rate of 300mL/min, and submersible-centrifugal pump at a "moderate" discharge rate of 1000mL/min, on trace metal concentrations.
4. Impacts of sampling device on particle size distribution and total concentration.

Impacts of these variables on the concentrations of major ions were also investigated, though not the major focus of this study. Also, although practical aspects of the sampling methods were considered, the evaluations were based primarily on the hydrogeochemical results.

To address the objectives, three field sites were visited: an active municipal solid waste landfill in Wisconsin, a closed solid waste landfill in Washington, and a site contaminated by industrial waste in Nevada. Three wells at the Wisconsin and Washington sites and two wells at the Nevada site were included in the evaluation. Although certainly not representative of geologic and hydrogeochemical conditions at all solid waste landfills and hazardous waste sites, these sites provided typical field conditions where traditional approaches to ground–water sampling produce turbid samples.

SECTION 2

CONCLUSIONS

1. Field determinations of the unstable parameters dissolved oxygen (DO) and turbidity were the most sensitive to disturbance of the sampling zone, with values produced by bailing often orders–of–magnitude higher than those produced by the pumps. Under low–yield conditions, the moderate–rate pumps also elevated DO and turbidity levels. In most other cases, however, pump type and discharge rate did not produce significant differences in these parameters. Elevated DO concentrations resulted from (a) aeration of the sampling zone and sample during collection by bailer and subsequent DO measurement, (b) aeration of the discharge tube when pump discharge was stopped because of operational problems with the submersible centrifugal pumps, and (c) aeration of the sampling zone during moderate–rate purging and sampling in low-yield wells. Elevated turbidity values were caused by (a) the action of purging and sampling with bailers, (b) surging discharge of submersible centrifugal pumps under certain hydraulic conditions, and (c) disturbance of the sampling zone during moderate–rate purging and sampling in low–yield wells. Variations in indicator parameters electrical conductivity (EC) and pH were insignificant between the four sampling methods, suggesting they were less related to disturbance of the sampling zone than DO and turbidity. Temperature showed little variation between the bladder pump and bailer but was highly elevated by the operation of the submersible centrifugal pump at low discharge rates. At wells not impacted by low-yield conditions or operational problems, the pumps provided equilibrium values of most indicator parameters at purged volumes of 12 to 32 L and within 10 to 15 percent of equilibrium values at purged volumes of 6 to 16 L. However, due to the nature of their operation, the bailers often did not produce equilibrium DO or turbidity conditions and the submersible centrifugal pumps often did not produce equilibrium temperature conditions. Likewise, under low–yield conditions, moderate–rate purging and sampling did not produce equilibrium DO or turbidity conditions. Although purging and sampling at low pump speeds reduced purged volumes from those typically experienced with bailers, the time required to complete purging was often considerably longer.

2. In-line filtration of pumped samples (by either 0.45–μm or 5.0–μm filter cartridges) did not significantly impact the concentrations of trace metals or major ions in the majority of cases. Filtered concentrations were generally not significantly lower than unfiltered concentrations, suggesting that relatively representative samples of the potentially mobile load were obtained in the unfiltered samples. The most obvious exceptions occurred at "turbid" or low–yield wells where moderate–rate pumping produced samples with the highest total particle concentrations of pumped samples. As a result of the elevated particle concentrations, trace metals that comprised these particles (such as oxides or hydroxides of iron), or that were associated with these particles (many aqueous species), were elevated in unfiltered samples, and were likely unrepresentative of mobile species. In contrast to the pumped samples, most bailed samples exhibited very large differences between unfiltered and filtered trace metals concentrations. In unfiltered samples, the high concentrations of particles suspended and entrained by bailing significantly elevated the concentrations of those trace metals associated with particles. In many cases, however, filtered bailed samples exhibited trace metal concentrations that were roughly equivalent to those produced in samples acquired using the pumps. Because bailers produced higher concentrations of potentially mobile particles, e.g., those in the 0.03 to 5.0 μm ranges, it may be concluded that the trace metals detected in this study were either not associated with colloidal transport or were associated with colloids smaller than 0.45 μm in size. The former seems more likely because bailing generally produced higher concentrations of sub-0.45-μm particles but not higher concentrations of trace metals in 0.45-μm-filtered samples.

3. Sample collection with the bailer generally caused significant differences in trace metal concentrations with respect to the pumps only for unfiltered samples. Entrainment of high concentrations of normally immobile particles by bailing resulted in concentrations of trace metals that were often many times higher than in unfiltered pumped samples. Concentration differences were less for metals species that were primarily dissolved and not associated with particles. Samples collected by the bailer and immediately filtered exhibited trace metal concentrations that were roughly equivalent to those produced by the pumps and in-line filtration. Few consistent or significant differences in trace metals or particle concentrations were observed between the bladder pump and centrifugal pump or the "low" discharge rate of 300 mL/min and the "moderate" discharge rate of 1000 mL/min with the centrifugal pump. It appears that potential differences in metals concentrations between these rates were masked by the overall low concentrations observed and the variability associated with experimental and analytical error. The only exceptions to this response occurred at a highly turbid, low–yield well where moderate–rate pumping entrained higher quantities of normally immobile particles, and associated metals, than low–rate pumping.

4. Disturbance of the sampling zone by bailing resulted in total particle concentrations that were significantly higher than those produced by the tested pumping methods. Total particle concentrations at wells not impacted by low-yield conditions or pump operational problems ranged from 2.8 to 41.1 mg/L in pumped samples and from 40.3 to 818 mg/L in bailed samples. Under the most turbid conditions, the bailer produced a concentration of 6970 mg/L while the highest pumped value was 1300 mg/L. The bailer also generally resulted in higher concentrations of potentially mobile particles, suggesting that concentrations of colloidally-associated contaminants could be biased when bailing disturbs the sampling zone and elevates turbidity. Regardless of collection method, samples with over 30 mg/L total particle concentration contained over 50 percent of their particle mass as particles larger than 5.0 μm and over 95 percent as particles larger than 0.45 μm.

5. The relationship of turbidity to particle concentration and its sensitivity to the purging process, relative to other indicator parameters, suggests that turbidity may be a useful indicator of relative particle concentrations between wells and of stabilization of particle concentrations during monitoring well purging. If mobile particles are thought to be important to transport of contaminants in ground water, use of field parameters such as pH, temperature, or EC as criteria for determining adequate sampling conditions may result in underpurging.

SECTION 3

RECOMMENDATIONS

1. This study included only a limited number of wells at three sites and therefore does not represent the wide variety of geologic and hydrogeochemical conditions likely to be present at all solid waste or hazardous waste landfills. As a result, more information is required from a variety of sites regarding the presence of colloidal particles and the importance of these particles in the transport of trace metals and other contaminants in ground water. A better understanding of colloidal transport processes in ground-water environments could be gained from research focused on describing hydrogeochemical conditions and colloid size distribution, composition, movement, and association with trace metals at a variety of solid waste and hazardous waste sites. A "survey" of existing sites could be conducted to investigate hydrogeochemical colloid-related conditions. Furthermore, controlled field experiments using colloidal tracers could be conducted to better understand transport processes.

2. Given that most of the trace metals detected in this study appeared to be of natural origin (the only exception being several metals at the Nevada site), it would be beneficial for resolution of questions regarding sampling and filtration to apply many of the same experimental techniques to several sites containing known metals contamination. Sites where there is suspicion of metals being transported in ground water via association with colloidal particles would be of particular importance.

3. Hydrogeochemical conditions, which are different at every point in the ground-water zone and at every individual well site, contribute to the variability in speciation of trace metals, the presence of mobile colloidal particles, and associations of metals to particles. As a result, it is important to understand the basic framework that these conditions produce on a site-specific, and well-specific, basis. Therefore, even "routine" interpretation of ground–water quality data should include careful analysis of physiochemical conditions. For example, redox conditions in part of a ground-water system may promote the formation of iron oxide colloids suitable for sorption and transport of trace metals, while in another part of the system these conditions may not be present. Filtration of samples collected from the system where colloids are present may remove an important fraction of the mobile contaminant load, while filtration of samples from that part of the system without colloids is unlikely to affect trace metals concentrations. Collection and analysis of redox data would be critical to interpreting the analytical results.

SECTION 4

MATERIALS AND METHODS

Three field sites were visited during the course of the study: an active municipal solid waste landfill in Wisconsin, a closed solid waste landfill in Washington, and a site in Nevada that is contaminated by industrial waste. Three wells at each of the Wisconsin and Washington sites and two wells at the Nevada site were included in the evaluation. One of the wells sampled at the Wisconsin site (WISC-1) was not included in the evaluation for reasons discussed below. The wells were chosen with assistance from officials of the local state regulatory agencies, and in the case of the Washington site, EPA Region X. Relatively shallow (less than 25 m deep), 5.08-cm-diameter monitoring wells were utilized to minimize purged volumes and times, simplify equipment requirements, and reduce the time required for equipment decontamination procedures. Wells that demonstrated high turbidity levels (over 100 Nephelometric Turbidity Units or NTU) and evidence of impact by metals transported in ground water were targeted for study. A summary of the well characteristics and hydrochemical conditions represented by bailed samples is presented in Table 1.

During the planning stages of the study, it was proposed that prior to our visit to each landfill, the landfill operators would collect ground-water samples as part of their usual monitoring program according to their standard operating procedures. Discussions with officials of state regulatory agencies and the EPA Office of Solid Waste revealed that these procedures most often consisted of sample collection with bailers and field filtration with 0.45-μm-membrane filters. Splits of these samples would then be submitted to the DRI laboratory for analysis of the same constituents to be analyzed during the pump experiments. The following week, we would conduct a suite of experiments in the same wells utilizing the submersible pumps. This approach was followed at the Wisconsin site but modified for the Nevada and Washington sites where routine sampling programs were not active. At these latter two sites, we collected samples using bailers and filtration techniques similar to those used at the Wisconsin site. Bailed samples were collected a week prior to the pump experiments at the Nevada site and subsequent to the completion of all the pump experiments at the Washington site.

Four methods of collecting samples from conventional standpipe monitoring wells were evaluated using three types of sampling devices and three pump discharge rates. The methods utilized at eight of the nine wells were: (1) bailer, (2) centrifugal pump at 300 mL/min (denoted in this report as CP1), (3) bladder pump at 500 mL/min at the Wisconsin site or 1000 mL/min at the other sites (denoted as BP), and (4) centrifugal pump at 1000 mL/min (denoted as CP2). Experiments at the ninth well (WISC-1) included only the bailer and the bladder pump at a discharge rate of 500 mL/min. Discharge rates were measured at ground surface and were controlled by the pump speed rather than by flow restrictors or valves. These discharge rates were used for both purging and sampling. Descriptions of the sampling devices are given in Table 2.

All devices were used in a portable mode. The centrifugal pumps were powered by either a 230 volt or 120 volt converter and a generator of at least 3000 watts, while the bladder pump was powered by compressed nitrogen gas using a pneumatic controller. Fill and discharge cycles of the bladder pump were approximately four seconds in duration and nitrogen delivery pressure was set between 20 and 35 pounds per square inch, depending on desired discharge rate and lift required at each well. Due to the pulsed discharge of the bladder pump, entrance velocities at

TABLE 1. SUMMARY OF MONITORING WELL CHARACTERISTICS AND HYDROGEOCHEMICAL CONDITIONS (DETERMINED FROM BAILED SAMPLES)

Well ID	WISC–1	WISC–2	WISC–3	WISC–4	NEV–1	NEV–1	WASH–1	WASH–2	WASH–3
Geologic Description.	Varved silty clay and clayey silt.	Silty sand. Fractured dolomite, moderately weathered.	Fractured dolomite, moderately weathered.	Silty clay with gravel. Fine to medium sand.	Coarse sand with clay. Clay with coarse sand.	Gravel and 30% sandy clay.	Silty fine sand. Fine sand with coarse sand and silt lenses.	Fine to coarse sand with gravel. Clayey silt and fine sand lenses with shells.	Gravelly medium sand with some silt. Fine sand with shells and trace of silty clay and fine gravel.
Install Date	1974	1988	1988	1988	1983	1987	1987	1987	1987
Construct.	2" dia. PVC	2" dia. PVC	2" dia. PVC	2" dia. PVC	4" dia. PVC	2" dia. PVC	2" dia. PVC	2" dia. PVC	2" dia. PVC
Well Intake Depth (m) [Intake Length]	9.5–11.0 [1.5]	18.6–23.2 [4.6]	17.7–22.3 [4.6]	3.4–6.4 [3.0]	3.0–9.0 [6.0]	5.8–6.4 [0.6]	12.2–15.2 [3.0]	3.2–5.2 [3.0]	2.4–5.4 [3.0]
Well screen Volume (L)	12	9.3	9.3	6.2	49.4	1.2	6.2	6.2	6.2
SWL (m)	5.02	14.07	14.44	0.93	2.93	2.90	11.51	2.03	2.26
Pump Intake Depth (m)	10.4	18.3	17.1	2.7	6.1	5.5	14.6	3.7	4.0
Field Parameter Measurements from Bailed Samples:									
T (°C)	12.7	12.2	9.8	14.9	24.3	22.3	10.6	9.4	9.5
pH	6.30	8.20	9.00	7.23	7.07	7.13	7.71	6.45	6.74
EC (µS)	1180	212	240	1490	22,600	21,600	886	113	687
DO (mg/L)	–	3.9	–	4.6	2.8	3.3	6.0	3.5	3.3
Turb (NTU)	–	170	195	> 2000	67.2	448	1156	735	10.3
Notes	Recovery time >24 hr. Well volume = 12 L.						Pumping level drawn down to pump intake during some sampling events		

the pump inlet were twice the referenced surface discharge rate. Discharge tubing for the pumps was 1.27-cm I.D. PTFE-lined polyethylene. The same piece of tubing was used for both pumps and was cut to the length required for the deepest sampling zone at each site. New tubing was used for each site.

TABLE 2. DESCRIPTIONS OF THE GROUND-WATER SAMPLING DEVICES

I.D.	Type	Brand	Materials	Discharge Rate
CP1	Submersible centrifugal pump	Grundfos Redi-Flo 2	Stainless steel body, PTFE-lined PE discharge tubing	Low (approx. 300 mL/min)
BP	Bladder pump	QED Well Wizard	PTFE body, PTFE-lined PE discharge tubing	Moderate (approx. 1 L/min, 500 mL/min at Wisc.)
CP2	Submersible centrifugal pump	Grundfos Redi-Flo 2	Stainless steel body, PTFE-lined PE discharge tubing	Moderate (approx. 1 L/min)
Bailer (Nev. and Wash. Sites)	Bailer, dual check-valve	Monoflex	PVC body, disposable PP haul line	Volume: 460 mL
Bailer (Wisc. Site)	Bailer, dual check-valve	Monoflex	PVC body disposable PP haul line	Volume: 3.5 L

The suite of pumping experiments in each well included the following primary elements. The low-flow-rate experiments were conducted first to minimize disturbance of the sampling zone. Upon completion of purging at the low rate, a full suite of samples was collected for analysis of particle size distribution, dissolved solids, organic carbon, and 0.45-μm-filtered and unfiltered metals and major ions. An additional set of samples at one well at each site were 5.0-μm-filtered to investigate the effects of removing from the sample only the suspended particles larger than 5.0 μm. Following sample collection, the pump and tubing were removed from the well, decontaminated, and installed in the next well. After completion of the low-rate experiments in all wells, the moderate-rate experiments were conducted. These experiments followed the same procedures as the low-rate experiments, with the exception of the pumping rate. Experiments in individual wells usually were separated by at least 24 hours.

Many of the specific sampling procedures followed in this study, as well as the general approach to acquisition of ground-water samples, are described in Desert Research Institute (1991). Procedures that differ from those presented in that document, as well as a brief overview of all procedures, are described here. Each well site was prepared prior to sampling by positioning the sampling support vehicle near the well head, spreading a plastic ground sheet around the well, and opening the well cover. The static water level in the well was measured with a flat tape water level probe.

If possible, the sampling device intake was positioned in the screened interval within 0.6 m of the top of the screen, however, low-yield conditions at several wells dictated that the device intake be set to greater depths (up to 1.5 m) to maintain adequate flow into the well and device. Once established, this depth was used for all devices. Measurements of field parameters were made during purging to evaluate the effectiveness of the purging method for minimizing disturbance of the sampling zone and removing stagnant water, as well as to provide an indication of when well purging was complete. Purging was considered complete and sample collection initiated when measurements of these parameters reached "stable values" over approximately one well-screen volume. Due to the nature of their design and operation, the bailers were often incapable of producing stable values of certain indicator parameters, particularly DO and turbidity. As a result, purging by bailer was considered complete when the other indicator parameters stabilized or when 3 to 5 well volumes had been purged. At the Wisconsin site, the volumes specified in the site sampling plan were used for purging with the bailers (approximately 4 casing volumes).

Use of the well–screen volume as the unit of measurement does not suggest that all stagnant water in the well bore, well screen, or sampling zone was replaced by fresh ground water during purging. On the contrary, purging at low to moderate rates in high–yield wells probably results in a certain degree of mixing of ground water with stagnant water in the well bore (see for example, Unwin and Maltby, 1988; Robbins and Martin–Haydon, 1991). As a result, the actual volume of the well screen is generally not directly related to the volume required to purge the well but does provide a useful benchmark for comparison of purged volumes between wells. Stabilization criteria were based on accuracy and precision data on instrumentation as supplied by the manufacturers, hydrogeochemical conditions at each well, past experience, and guidelines suggested by Gibs and Imbrigiotta (1990), and are given in Table 3.

TABLE 3. CRITERIA FOR STABILIZATION OF INDICATOR PARAMETERS DURING PURGING

Field Parameter	Stabilization Criterion
Dissolved Oxygen	0.10 mg/L
Electrical Conductivity	3% Full Scale Range
pH	0.10 pH unit
Temperature	0.2 ° C
Turbidity	1.00 NTU

When purging was considered complete, the pump discharge line leading to the flow-through cells was disconnected, the pump speed was readjusted to obtain the desired discharge rate, and the discharge was directed into sample bottles for the unfiltered samples or through high-capacity in-line filter cartridges for the filtered samples. Bailed samples from the WISC wells were transferred to a polycarbonate holding vessel (Geotech Environmental Equipment, Inc.) fitted with a 102–mm–diameter, 0.45 µm membrane filter, while samples bailed from the NEV and WASH wells were transferred to a holding vessel composed of polycarbonate, polypropylene, and polyvinylchloride (QED, Inc.), and fitted with the appropriate pore-size in-line filter cartridge. In both cases, compressed nitrogen was used to pressurize the holding vessel and force the sample through the filter. The 0.45-µm in-line filter cartridges (Geotech Environmental Equipment, Inc.) utilized Versapor® (acrylic copolymer on a nylon support) membranes and a polypropylene body, the 5.0-µm in-line filter cartridges (QED, Inc.) utilized nylon membranes and a polypropylene body, and the 0.45–µm membrane filters were composed of polycarbonate. In-line filters were flushed with approximately 500 mL of sample water to remove membrane preservatives and wetting agents before the filter discharge was directed into sample bottles. Including the volumes that passed through the filters for the major ion, dissolved solids, and organic carbon samples, approximately 3.5 L of water had passed through the filter membranes before the metals samples were collected. Filter clogging during filtration of highly turbid samples was experienced only with the 102–mm membrane filters (bailed samples at WISC Wells), requiring replacement of the filter during the filtration process.

Turbidity was measured with a direct-reading Nephelometric meter (HF scientific, inc.) utilizing a flow-through cuvette for pump discharge and a standard 28-mm cuvette for bailer discharge. The instrument provides a linear display of turbidity in NTUs. Calibration was accomplished prior to visiting each site using standard Formazin solutions, while standardization with a 0.02-NTU reference standard was conducted prior to each sampling event. DO, temperature, pH, and EC of pump discharge were measured using a flow-through cell and meter system (QED, Inc.). Measurements of turbidy and pH were more difficult with the bladder pump due to the pulsed discharge. Measurements of bailer discharge were made using the same probes and meter but a beaker was used in place of the flow-through cell. Calibrations of DO and pH were conducted immediately prior to the initiation of each sampling event and pH was checked after sample collection was complete. A 100 percent humidity calibration was used for DO and a three-point calibration for pH using 4.01, 7.00, and 10.01 buffers. Conductivity was calibrated at the beginning and end of each sampling day using a two- or three-point calibration of standards that bracketed the conductivity values of the ground water to be sampled. Oxidation–reduction conditions (Eh) were measured off-line using a silver/silver chloride reference electrode and a platinum working electrode. Eh calibration was carried out prior to each sampling event using a Zobell reference solution.

Samples for analysis of major ion chemistry, organic carbon, and dissolved solids were collected in duplicate in 1-L high density polyethylene (HDPE) bottles, while samples for analysis of metals were collected in duplicate in 250-mL Nalgene® HDPE bottles. Metal samples were preserved with a sufficient volume of nitric acid to reduce sample pH below 2.5. Samples for analysis of particle size distribution were collected in 4-L HDPE Cubitainer® containers. All bottles were pre-cleaned to meet or exceed U.S. EPA Contract Laboratory Program analyte specifications and detection limits and rinsed with a small quantity of sample water before sample collection. Precautions were taken to minimize disturbance of the samples and contact with air during sample collection. Upon collection, samples were sealed, labelled, and packed in ice chests with packing foam and ice for overnight delivery to the analytical lab.

All laboratory analyses were conducted at the DRI Water Analysis Laboratory in Reno, Nevada. Determinations of sodium, potassium, calcium, and magnesium were made by direct aspiration atomic absorption (U.S. EPA, 1979); alkalinity by automated electrometric titration (U.S.G.S., 1979); sulfate by ion chromatography (U.S. EPA, 1984); nitrate by automated cadmium reduction colorimetry (U.S. EPA, 1979); chloride by automated ferricyanide AAI colorimetry (U.S. EPA, 1979); and silica by automated molybdate blue colorimetry (U.S.G.S., 1979). Barium, chromium, iron, and nickel were analyzed by direct aspiration inductively coupled plasma (U.S. EPA, 1979); cadmium, manganese, and lead by direct aspiration atomic absorption (U.S. EPA, 1979); and arsenic by hydride generation atomic absorption (U.S.G.S., 1985). Analytical precision and bias were evaluated using the procedures outlined in "Standard Methods for the Examination of Water and Wastewater" (1992). Within every analysis set, a minimum of 10 percent laboratory–spiked samples, 10 percent laboratory duplicate samples, and 5 percent EPA reference samples and/or natural water control samples were analyzed. Precision data for each analysis are presented in Table 4. The quality control limits consist of a warning limit of 2 times the standard deviation and a control limit of 3 times the standard deviation. Samples exceeding the control limit were reanalyzed. No evidence of analytical bias was detected and all results fell within the established quality control limits.

Estimates of particle grain size distribution were determined gravimetrically by serial ultrafiltration using EPA Method 160.2 (U.S. EPA, 1984) and microfilters of 5.0 μm, 0.4 μm, 0.1 μm, and 0.03 μm pore size. The analytical detection limit for this method was 0.1 mg/L.

The results were examined by multivariate and univariate analyses of variance using the BMDP (BMDP Statistical Software, Inc., 1988) and Minitab (Minitab, Inc., 1989) software packages. The study was treated as a complete randomized block design, with wells as blocks and the various device–filtration method combinations as treatments. The replicate observations of each treatment allowed computation of experimental error as well as sampling error.

The distribution of species in equilibrium under the hydrogeochemical conditions observed at each well were estimated using the geochemical modeling program PHREEQE (Parkhurst et al., 1980). Thermodynamic data were those provided with the program and those compiled by Drever (1982) and Woods and Garrels (1987).

TABLE 4. ANALYTICAL METHODS AND QUALITY CONTROL DATA

Constituent	Method	Method Detection Limit (mg/L)	Control Average (mg/L)	Percent Deviation
pH	EPA 150.1	0.02	8.47	0.4
EC	EPA 120.1	2.2	224	0.7
HCO3	USGS I–2030–78	1.6	128	0.5
C1	EPA 325.1	0.2	90.2	1.7
SO4	EPA 300.0	0.1	10.0	0.2
Na	EPA 273.1	0.01	10.0	1.6
K	EPA 258.1	0.01	9.4	1.5
Ca	EPA 215.1	0.03	70.8	1.8
Mg	EPA 242.1	0.01	18.5	1.6
Si	USGS I–2700–78	0.05	71.6	1.8
NO3–N	EPA 353.2	0.003	1.4	2.0
TDS	EPA 160.1	2.0	168	2.6
TOC	EPA 415.1	0.2	26.1	4.7
As	USGS I–3062–85	0.001	0.21	6.8
Ba	EPA 200.7	0.002	1.0	1.6
Cd	EPA 213.1	0.002	0.026	7.5
Cr	EPA 200.7	0.01	0.15	2.1
Fe	EPA 200.7	0.01	0.078	6.1
Pb	EPA 239.1	0.02	0.11	10.2
Mn	EPA 243.1	0.01	0.34	1.2
Ni	EPA 200.7	0 01	0.10	6.8

SECTION 5

RESULTS AND DISCUSSION

Field hydrogeochemical conditions and particle concentrations, both site-specific and device-specific, provide the framework for interpretation of the metals data. For this reason, field parameters, particle size distributions, and total particle concentrations will be presented first, followed by the trace metal and major ion results.

IMPACTS ON FIELD PARAMETERS

Three important factors that influence the accuracy of field measurements of unstable parameters during sampling from conventional standpipe monitoring wells are sampling method measurement techniques, and hydraulics of the well. Evaluation of the impacts introduced by selected sampling methods was one of the primary objectives of this study and will be discussed below. Impacts related to measurement techniques were considered low because a single individual conducted all the field measurements and all procedures followed established protocol.

In contrast, well hydraulics had an impact on values of field parameters in some of the sampling events that masked all other factors. In particular, when the discharge rate of the sampling device exceeded the yield of the well, drawdown occurring in the well caused one or both of the following responses. First, increased hydraulic gradients disturbed the sampling zone and mobilized large volumes of particles into the well, thereby elevating turbidity values. DO levels also increased as dewatering of the filter pack created a larger air-water interface for transfer of oxygen. These factors led to highly biased equilibrium values and/or greatly increased purged volumes, as demonstrated at WASH-1 where discharge rates of approximately 1.0 L/min caused dewatering of the filter pack and concomitant increases in turbidity and DO (Figure 1). Note that the lower discharge rate, which was probably closer to the yield of the well, resulted in lower variability in these parameters.

Second, performance of the centrifugal pumps decreased as drawdown and therefore total head on the pump system increased, sometimes leading to a complete loss of discharge. Resumption of pump operation was often accompanied by a large surge and large changes in several indicator parameters, particularly turbidity and DO. Like dewatering the filter pack, this effect resulted in biased equilibrium values and/or increased purged volumes. In addition, operation of the centrifugal pump at low discharge rates caused noticeable increases in discharge temperature. This response was most pronounced at WISC-4 where the yield was sufficient to prevent dewatering of the filter pack and screen but not to prevent drawdown in the well. As a result, CP1 sampling at this well was complicated by variations in discharge rate which impaired the ability to reach equilibrium values of turbidity, DO, and temperature, and greatly increased purged volumes (Figure 2).

The yield of well WISC-1 was low enough that more than 24 hours were required after purging for the well to refill. In addition, the limited volume of water available prevented measurement of all field parameters and collection of the full suite of samples. For these reasons, and because the well hydraulics greatly differed from other wells in the study, only limited sampling was conducted there and the results were not included in the statistical analysis.

High-yield wells, such as NEV-2 (Figure 3), produced less variable results than the wells discussed above, with the exceptions of pump discharge temperature and several field parameters from the bailer.

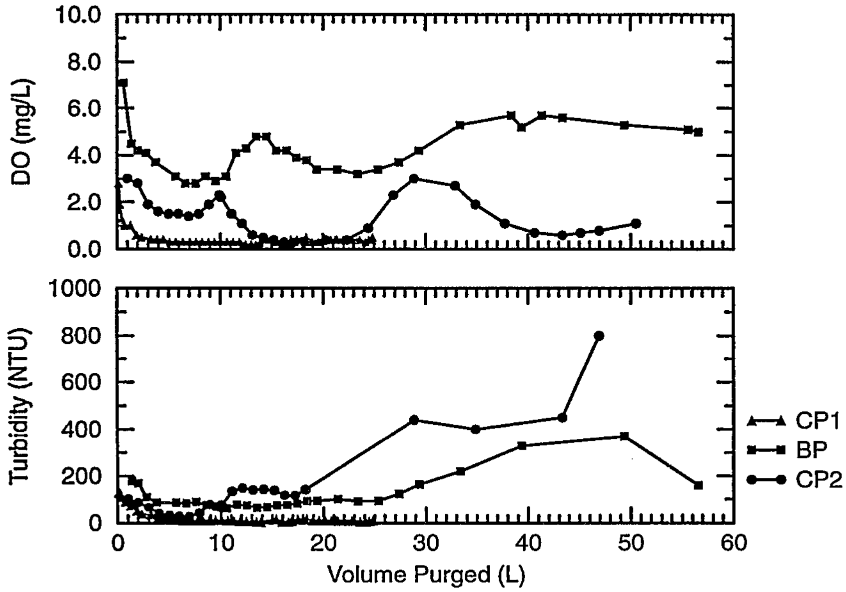

Figure 1. Impacts of dewatering filter pack on turbidity and dissolved oxygen at WASH-1. Note the lower and stable values of dissolved oxygen and turbidity at the discharge rate of 300 mL/min (CP1). Significant dewatering of the filter pack occured at 22 L for BP and CP2.

DO concentrations were consistently higher in bailed samples than pumped samples (Figure 4 and Appendix A). Bailing produced DO concentrations of approximately 3.0 to 5.0 mg/L, 10 to 20 times higher than final pumped concentrations in the higher-yield wells, and showed minimal decline during purging. In contrast, the pump methods typically produced maximum values at the initiation of pumping (between approximately 25 and 50 times higher than final values in higher-yield wells) followed by an exponential decline to equilibrium values. The DO response observed in the pump results is consistent with the progressive removal of stagnant DO-charged water in the well, pump body, and discharge tubing.

As these results demonstrate, the concentration of DO and its variability during the well purging process is often highly sensitive to sample collection method. Sampling devices that excessively agitate the sample and/or the sampling zone may lead to aeration of the sample and elevated DO concentrations. For example, bailers subject their samples and the water column within the well to considerable agitation and aeration as the bailer is lowered and raised from the sampling zone. Sample aeration may also occur when the samples are transferred to a beaker for indicator measurements and during the time measurements are conducted. Additionally, oxygen (and other gases) may diffuse through the flexible tubing used for submersible pump discharge (Holm et al., 1988), although this effect appears to occur on a much smaller scale. Enrichment of DO during the sampling process not only produces samples that are unrepresentative with respect to oxygen but may result in oxidation and subsequent precipitation of reduced species, such as ferrous iron, and coprecipitation of other metals species. Alteration of dissolved constituents in this way during sampling may lead to erroneous conclusions about their concentrations or speciation.

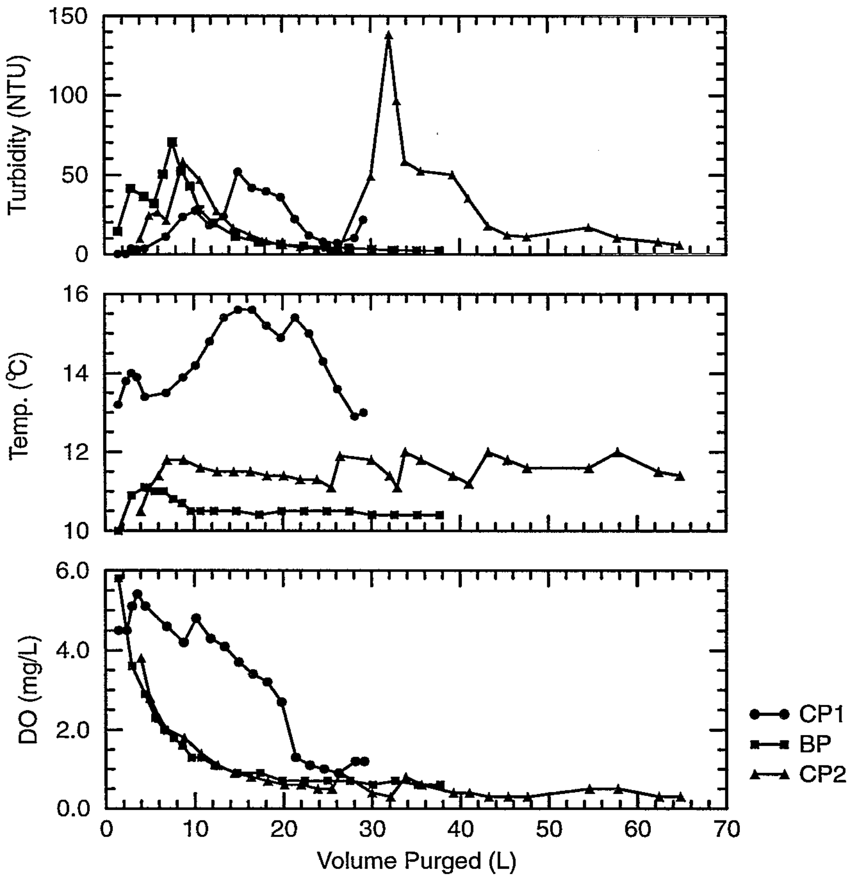

Figure 2. Impacts of variations in discharge rate of CP1 and CP2 on equilibration of field parameters at WISC-4. In contrast, note relatively smooth response of BP.

Equilibrium DO concentrations appeared to depend on hydraulic conditions of the well and not pump type or discharge rate. In the moderate- to high-yield wells, the pumping methods all produced DO concentrations of 0.4 mg/L or less. In lower-yield wells (WISC-4, WASH-1), DO concentrations were much higher as drawdown introduced more oxygenated water to the pump intake.

Although volumes required to reach equilibrium DO concentrations varied between the pumps, there were no consistent relationships. On the other hand, the pumping methods attained DO equilibrium before the bailer, which reached equilibrium at only one well. The nature of the bailing process causes considerable variability in DO concentrations between subsequent bails, thereby often preventing equilibrium DO conditions. At six wells, pumping required removal of 4.4 to 23.6 L to reach equilibrium DO concentrations (Figure 5 and Appendix A), corresponding to less than 3.8 screen volumes for five of the wells and 10 screen volumes for NEV-2, which had a screen volume of only 1.2 L. The higher purged volumes at WISC-4 were related to operational problems with CP1 and CP2, and at WASH-1 the higher volumes were due to low well yield. For the pumps, the purged volumes required to reach DO equilibrium were higher than for all other indicator parameters except turbidity and CP1/CP2 temperature. These results indicate that DO is sensitive to the purging process and further suggest that DO may be an important indicator of the volume required to remove stagnant water from the sampling system.

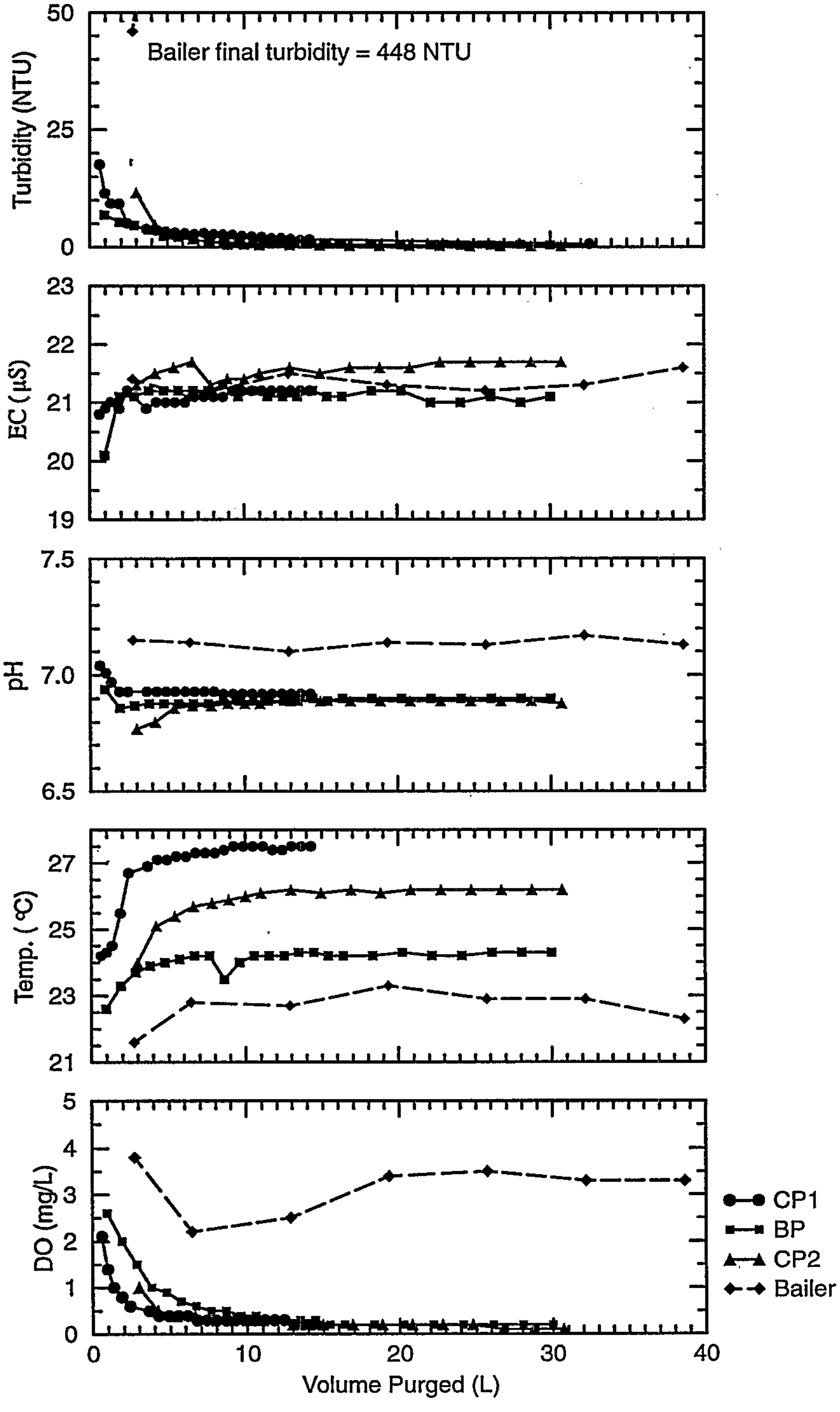

Figure 3. Trends of field parameters in high-yield well NEV-2.

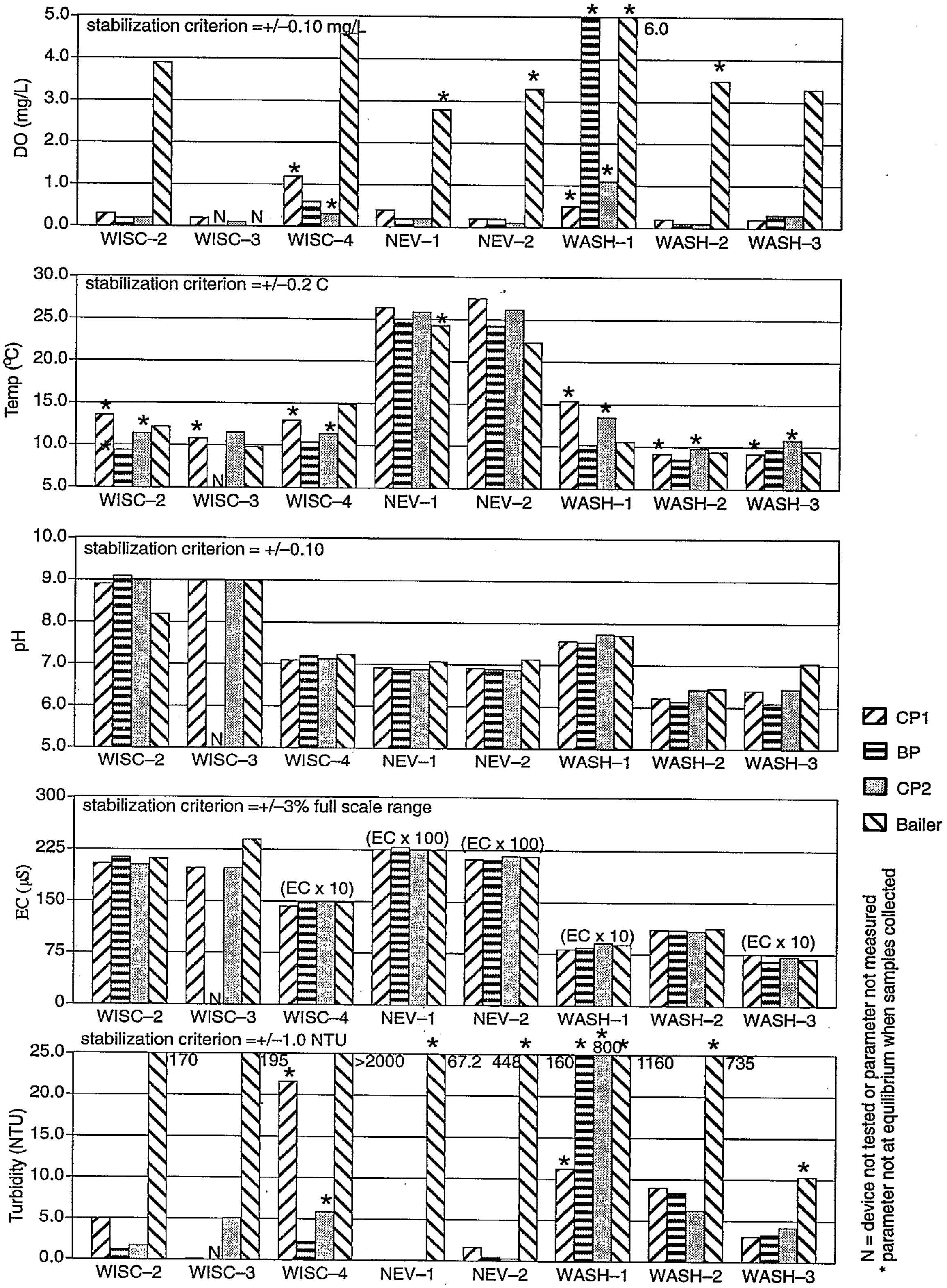

Figure 4. Equilibrium values of field parameters (note that parameters of bailed samples at the WISC wells were measured only at time of sample collection).

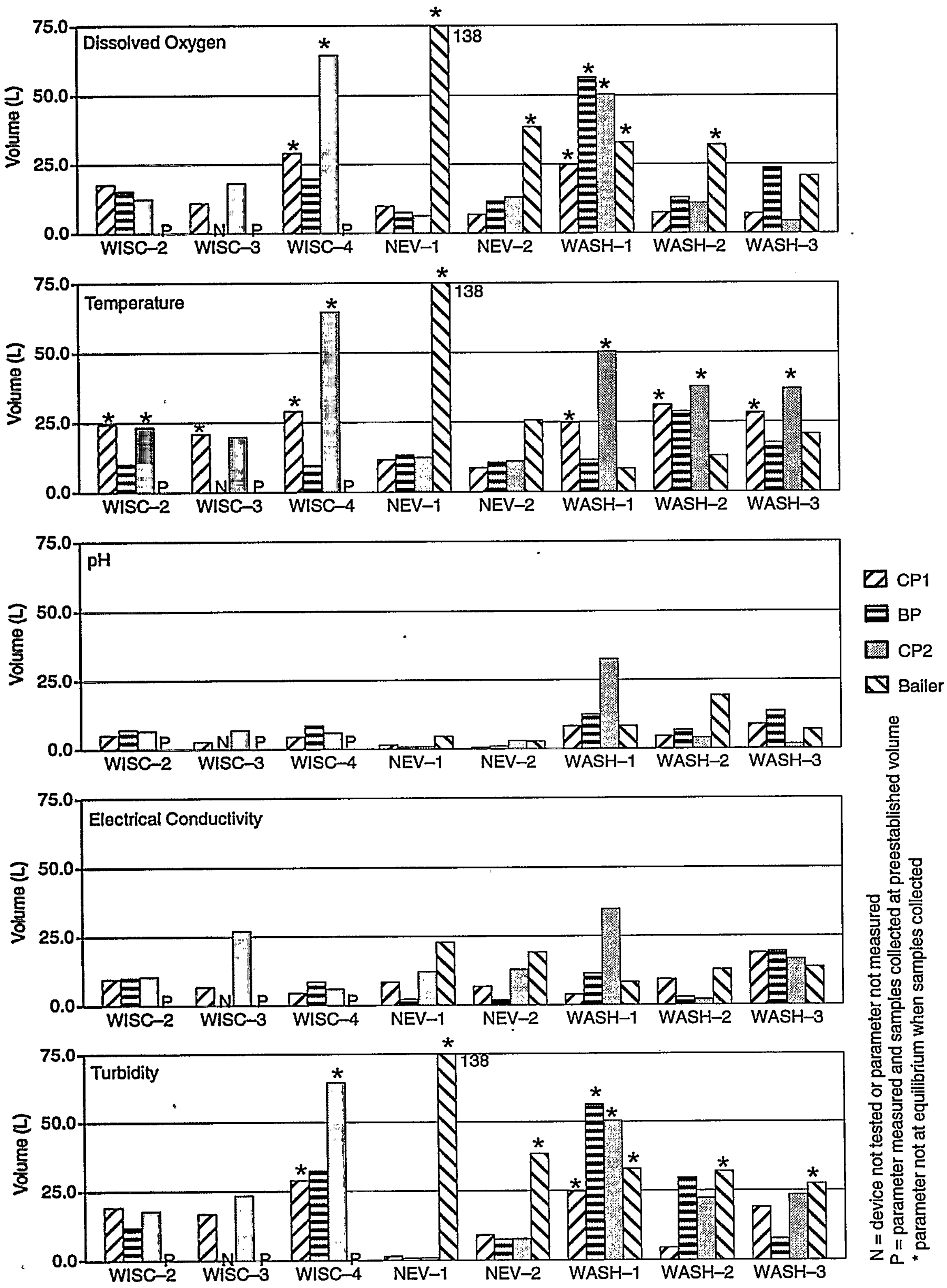

Figure 5. Purged volumes required to reach equilibrium values of field parameters.

As with DO, turbidity exhibited a strong dependence on sampling method. The highest turbidity values were obtained with the bailers, while the lowest turbidities were obtained with the pumps. In fact, the highest bailed turbidity values obtained were as much as two orders–of–magnitude greater than samples pumped from the same well. Equilibration of turbidity, like DO and Eh, is often related to sample collection method. Agitation of the sampling zone by motion of the sampling device (as with a bailer) often suspends and entrains particles in the sample discharge leading to elevated sample turbidity. Additionally, discharge rates that exceed the yield of the water-bearing zone may mobilize normally immobile particles, leading to elevated turbidity and biased analyses of trace metals and other ions. Even with very careful operation, the repeated motion of the 4.1-cm-diameter bailer inside 5.1-cm-diameter casing and screen caused a surging action that mobilized significantly more particles than were mobilized with the pumps. In addition, bailer-produced turbidity values showed considerable variability between measurements and often did not reach equilibrium values, indicating the bailing process was significantly disturbing the sampling zone.

With the exception of those wells where steady discharge could not be maintained (discussed below), turbidity values during pumping generally followed a trend of maximum values at the initiation of pumping followed by an exponential decline to equilibrium values. The initial maximum may result from particles formed or collected within the well casing between sampling events as described by Backus et al. (1993), disturbance of the sampling zone during emplacement of the portable pumps as observed by Kearle et al. (1992), or particles mobilized and then settled out after previous sampling by bailers.

Evaluation of the turbidity data from the pumps was complicated by operational problems experienced with the centrifugal pump, the hydraulic responses of the lower-yield wells, and the order in which the experiments were conducted. In wells where a steady discharge was difficult to maintain with the centrifugal pump (particularly WISC-4 and WASH-2), variation in discharge rate occurred during the adjustment of the pump speed. These variations were occasionally high enough to mobilize and entrain particles that had previously been undisturbed, thereby elevating turbidity and increasing the volume required to reach equilibrium. In the case of WISC-4, operational problems prevented equilibrium from being reached for turbidity, DO, and temperature. Hydraulic conditions at low-yield well WASH-1 presented a different problem but with similar results. The low yield of this well caused significant drawdown and dewatering of the filter pack when purging at rates greater than at least 900 mL/min (the lower rate caused drawdown but did not dewater the filter pack to the pump intake). As the filter pack was dewatered, the increased hydraulic gradient and agitated conditions in the water-bearing zone appeared to have mobilized normally undisturbed particles leading to increased turbidity values. Finally, the order in which the experiments were conducted in each well may also have effect time to equilibration and final turbidity values. As previously discussed, sampling events using low discharge rates were conducted prior to the moderate rate events in seven of the eight wells and bailer samples were collected prior to pumped samples in four wells. In addition, all the wells had been extensively sampled with bailers prior to this study. It is likely that a significant fraction of particles present in the well, filter pack, and adjacent water-bearing zone at the initiation of the low rate pump experiments were an artifact of earlier bailing events. As a result, the first pump experiment may have acted as further "development" of the sampling zone, causing higher initial turbidity values and longer times to equilibration during the first pump experiment.

Omitting the pump experiments where turbidity was highly dependent on well hydraulics and/or pump performance (WISC-4 and WASH-1), equilibration was attained after pumping 0.7 to 29.8 L (corresponding to approximately 2 to 7.7 screen volumes). Variation was evident in final turbidity values and times to equilibration for the pumps but no distinct relationships between device and these parameters existed. The differences were all within +/- 5.0 NTU.

Values of pH showed little variation between pump methods with most values falling within the range of +/- 0.2 pH units for a given well. Bailed pH values were also within this range but were usually higher than pumped values, possibly reflecting degassing of CO_2 from the samples during collection and pH measurement. In addition, pH reached equilibrium at lower purged volumes than all the other parameters, independent of sampling method. Although pH is an important indicator of the speciation of trace metals in ground water, the relatively uniform values across devices at individual wells do not alone suggest that similar metals species might be present. Other factors, such as redox conditions and particle concentration, may play more important roles.

Impacts of sampling on ambient ground-water temperature were due to: (1) equilibration between the sampling device temperature and ground-water temperature subsequent to installation of the device in the well, (2) removal of stagnant water from the well of a temperature different from ambient ground water, (3) air temperature changes during sampling, and (4) heat generated by operation of CP1 and CP2. The first two factors were resolved by the purging process, the third was minimized but not eliminated by limiting the length of tubing used with the pumps, and the fourth was related to the operational design of the centrifugal pumps. Equilibrium temperatures of BP and bailer discharge typically were similar for the same wells at the Nevada and Washington sites, following a smooth trend from stagnant conditions. Bailer temperatures were more variable at the Wisconsin site because sampling procedures and measurement method were slightly different there. In contrast, equilibrium temperatures of the centrifugal pumps, CP1 in particular, were as much as 5.2 °C higher than BP values for the same well. CP1 and CP2 discharge temperatures also showed considerable variation in response to changing pump discharge rates during purging. This effect of elevated temperatures appears to have been caused by heat produced from the pump motor operation and was exacerbated at lower discharge rates when less water passed over the motor housing.

For the BP and bailer, volumes purged to reach equilibrium temperatures were generally lower than for turbidity and DO. The elevated temperatures associated with CP1 and CP2 caused purged volumes to be approximately equal or greater than for the other indicator parameters, with the exception of turbidity. In most cases, temperatures of CP1 and CP2 did not reach equilibrium.

EC is generally considered to be independent of sampling method (when appropriate materials are utilized in the construction of the device) because there is little opportunity for the device to impact sample quality. With few exceptions, equilibrium conductivity values produced by the four methods were within +/- 5 percent of full scale range. Furthermore, purged volumes required to reach equilibrium were lower than for all other parameters except pH, indicating that under these conditions EC may not be indicative of purging completion.

Measurements of Eh should reflect the intensity of oxidizing or reducing conditions in the ground-water environment but are often significantly altered by sample collection method. In situ ground water is generally considered to be at a relatively stable redox state, but when samples are exposed to air, the redox system may be overwhelmed by reactions involving oxygen (Hem, 1985). Eh is an important control on the distribution of species in ground water and changes in Eh during sampling may alter the dominant species present. Sampling methods that result in excessive exposure to air may increase Eh and cause shifts from dissolved species to solids (precipitates) that may be removed during filtration. Additionally, elevated Eh values may lead to incorrect conclusions about the distribution of species in the ground water. In this study, variability in Eh measurements generally masked any distinct trends that might have been related to the effects of sampling method, although the bailer often produced Eh values that were slightly higher than those obtained with the pumps. By contrast, the lower extent of disturbance of the sampling zone assumed to be associated with CP1 did not lead to lower, or presumably more representative, values of Eh. Volume purged to reach equilibrium Eh values was not available because the parameter was not used as a purging criterion and for that reason was not measured continuously.

IMPACTS ON PARTICLE SIZE DISTRIBUTION AND CONCENTRATION

Particle concentration and size distribution were analyzed in the laboratory by serial ultrafiltration. This method provides a reasonable approximation of particle size distribution (Kingston and Whitbeck, 1990), but is dependent on sample handling and analytical holding times which may skew the data toward larger particle sizes through precipitation, nucleation, and aggregation processes. For this reason, the analytical error of $\pm$ 1.0 mg must be kept in mind when interpreting the particle size results. The total concentrations and size distributions of particles entrained in samples were expected to be related to hydrogeologic conditions and well construction details at each well site and certain sampling variables, particularly sampling device type and discharge rate. Total particle concentrations in samples pumped from the higher-yield wells ranged from values below 2.8 mg/L at WISC-2 and WISC-3 up to values between 8.9 and 41.1 mg/L at WASH-2 and WASH-3 (Figure 6 and Appendix B). Concentrations at NEV-1 and NEV-2 were between 2.7 and 13.3 mg/L. Because essentially the same sampling techniques were utilized at each site, the observed range in particle concentrations between the sites may reflect differences in methods of well installation, well development, sampling history, and hydrogeologic and hydrogeochemical conditions in the water-bearing zone.

Sampling device had an important effect on total particle concentration and particle size distribution at most wells. Samples bailed from the higher-yield wells exhibited particle concentrations ranging from 40.3 mg/L at WASH-3 to 818 mg/L at WASH-2. Even greater concentrations were obtained when bailing from the lower-yield wells; 845 mg/L at WASH-1 and 6970 mg/L at WISC-4. At six of the wells, the bailers produced total particle concentrations that ranged from 6.5 to 17,000 times greater than those produced by the pumps in the same well. Of the two remaining wells, WASH-3 particle concentrations showed little variation between the devices (a range of 39.1 to 41.1 mg/L) and WASH-2 results were heavily influenced by well hydraulics and pump operation causing CP1 to produce the highest concentrations.

In addition to generally higher total concentrations, particle size distributions of bailed samples were highly skewed toward particles greater than 5.0 μm in diameter. The bailed samples usually contained over 90 percent of particle mass in the fraction retained by the 5.0–μm filters, while the pumped samples contained a more uniform distribution of particle sizes. The surging action of the bailer as it passed through the water column clearly mobilized more and larger particles than most of the tested pumping methods which generally minimized disturbance of the sampling zone. However, pumped samples from WISC-4 and WASH-1 that contained relatively high particle concentrations also showed size distributions that were skewed toward the larger particles. Samples exceeding 30 mg/L total particle concentration, regardless of sampling device, contained at least 50 percent by weight of particulate matter over 5.0 μm in size and 95 percent by weight of particulate matter over 0.4 μm in size.

High concentrations of particles larger than 5.0 μm are more likely related to geologic conditions, drilling methods, and well installation procedures than ground-water contaminant transport and may bias analytical determinations of mobile trace metals if not removed from samples. On the other hand, particles smaller than 5.0 μm are potentially mobile in many ground-water environments and may be associated with contaminant transport. The 5.0–μm filters removed 75 to nearly 100 percent of the particles in bailed samples, corresponding to 30 to 6960 mg/L of solids. From 0 to 70 percent of the particles were removed from the pumped samples, although this corresponded to less than 2.2 mg/L from samples containing less than 30 mg/L total particle concentration, or up to approximately 30 mg/L from samples containing up to 50 mg/L total particles. In addition to the significant particle mass present as particles larger than 5.0 μm, the bailer also produced concentrations of particles between 0.03 and 5.0 μm (referred to here as sub-5.0 μm particles) that were up to 17 times higher than the mean concentration produced by the pumps at the same well. As an example, the pumps at WISC-2 produced a mean concentration of sub-5.0–μm particles of 0.5 mg/L, while the bailer produced 8.7 mg/L. This type of relationship was less evident at the WASH wells where a much greater range in particle size distribution was observed.

The presence of measurable concentrations of sub-5.0-μm particles further suggests that removal of a fraction of them by 0.45 μm filtration might bias analytical determinations of mobile contaminant loads. In many samples from the WASH wells, concentrations of 0.4 to 5.0-μm particles were higher than concentrations of sub-0.4-μm particles, indicating that a majority of the particle load would be removed by 0.45-μm filtration. At the WISC wells, the fraction of 0.4 to 5.0-μm particles was roughly the same as the fraction of sub-0.4-μm particles, indicating that 0.45-μm filtration could conceivably remove half of the potentially mobile particles. At the NEV wells, a larger fraction of sub-5.0-μm particles were smaller than 0.4 μm so filtration might have less impact on mobile particle concentrations at this site.

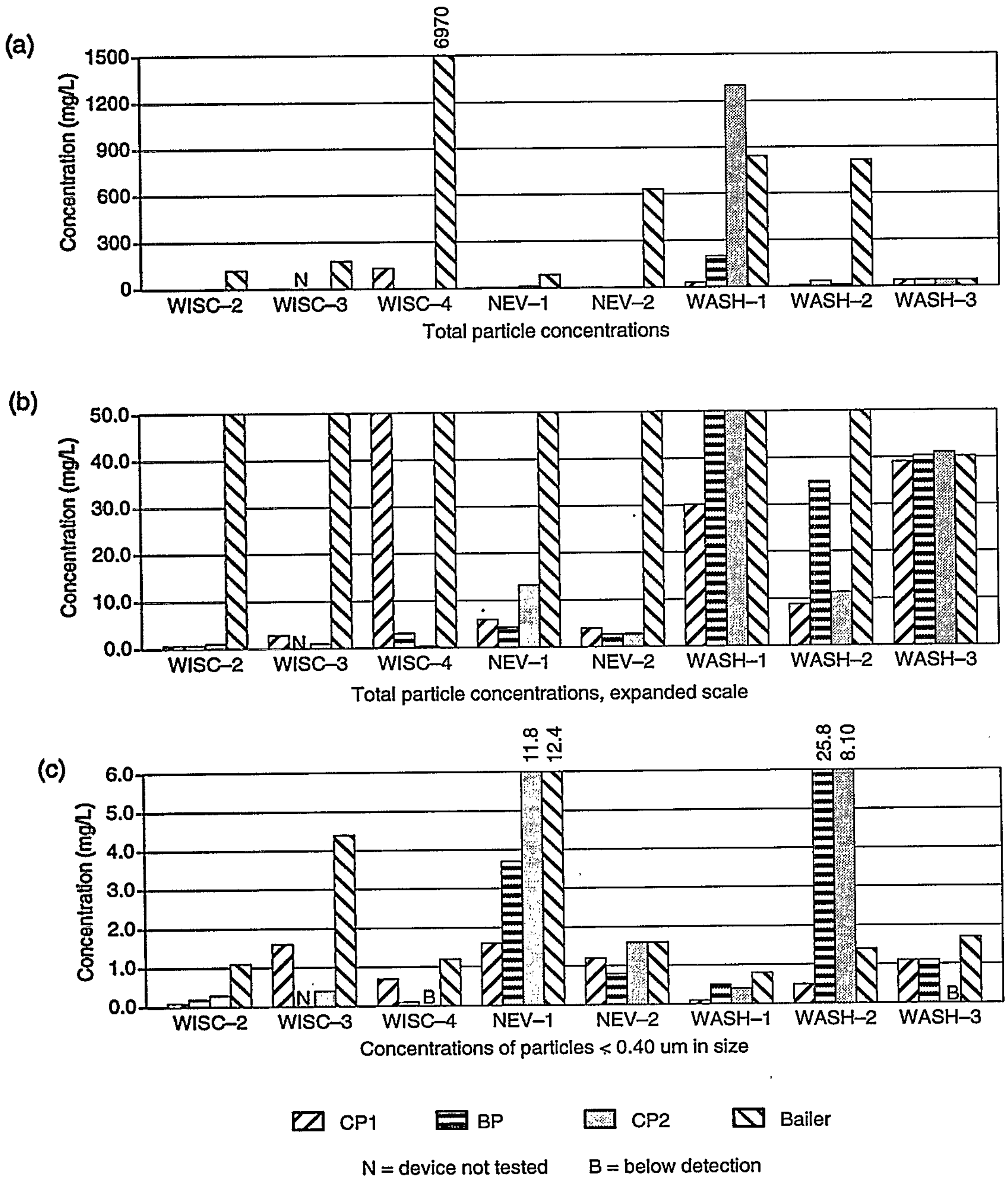

Figure 6. Results of particle analyses: (a) total particle concentrations; (b) total particle concentrations, expanded scale to show results of pumped samples; (c) concentrations of particles less than 0.4 μm in size.

Differences in concentrations of sub-0.4-μm particles between bailers and pumps were less than for sub-5.0-μm and total particles but the bailers still produced higher sub–0.4 μm particle concentrations at seven of the eight wells. Bailed samples contained sub-0.4-μm particle concentrations from 0.4 to 6.7 mg/L higher than the mean values of the pumped samples from the same well (Figure 6), suggesting that determinations of colloidally-associated contaminants might be biased.

Although distinct differences in both size distribution and total particle concentration were evident between the pumped samples (taken as a group) and the bailed samples, there were no consistent correlations between particle content and pump type or pump discharge rate. Under the conditions of these experiments, collecting samples at a discharge rate of 1000 mL/min did not consistently mobilize more or larger particles than collecting samples at 300 mL/min. Likewise, individual pumps did not produce consistent particle size distributions or concentration relationships. Interpump variability of these factors appeared to be caused by external effects such as order of the experiments, disturbance of the sampling zone during pump installation, well hydraulics, and other sampling and analytical errors.

A general relationship between turbidity and total particle concentration was observed, particularly for the higher particle concentrations (Figure 7). As a rule, the methods that produced samples with the highest particle concentrations also produced the highest levels of light scatter, and therefore turbidity, in the field. The apparent non-significant linear regression (although there was no lack of fit) observed for samples with particle concentrations less than 50 mg/L may be a result of deviations from the best-fit line caused by several factors. First, the distinct ground-water color at both Nevada wells might have reduced apparent turbidity values by reducing the amount of scattered light measured by the turbidimeter. Turbidity measurements at the NEV wells were consistently lower than at the WISC wells, despite higher particle concentrations. Second, the first pump experiment in each well almost always produced the highest turbidity of the three pumps in that well, while the particle concentrations were virtually the same as in the other pump experiments. This may be an artifact of the bailing process which occurred before the pump experiments in the WISC and NEV wells or natural colloid accumulation (particularly in the WASH wells where bailing was conducted after the pumped samples were collected). These factors might have caused accumulation of large numbers of particles less than 0.03 μm in diameter which were not detected in the particle size analysis but contributed to light scattering in the turbidity measurements. Finally, oxidation of dissolved ferrous iron in particle samples from the Washington wells may have elevated total particle concentrations in these samples, particularly WASH-3 which showed total iron concentrations of 17 to 21 mg/L. This process would not affect the in-line turbidity measurements and therefore would lead to deviations from the best-fit line.

It is important to keep in mind that the overall turbidity/particle relationship presented here includes the effects of four sampling methods at eight wells at three study sites. Despite this, the general relationship of turbidity to particle concentration strongly suggests that turbidity provides a useful indicator of the relative presence of particles in ground water. Furthermore, utilizing a single sampling device or sampling at an individual well would likely reduce or eliminate much of the variability described above. As a result, the relationships of turbidity to particle concentration and the sensitivity of turbidity to the purging process, relative to other indicator parameters, suggest that turbidity may be a useful indicator of the stabilization of particle concentrations during monitoring well purging. If mobile particles are thought to be important to the transport of contaminants in ground water, use of indicator parameters such as pH, temperature, or EC to determine representative sampling conditions may result in underpurging, and consequently, the collection of inaccurate samples.

IMPACTS OF FILTRATION ON METALS CONCENTRATIONS

Of the seven metals targeted for study, lead and cadmium were not detected in samples from any of the wells and concentrations of the other five were generally below 50 μg/L. Iron was an exception in that it was detected in concentrations up to 71 mg/L. The low concentrations of most of the targeted metals suggests that analytical variability may be an important contributor to the overall variability observed in the metals data. For example, at the detection

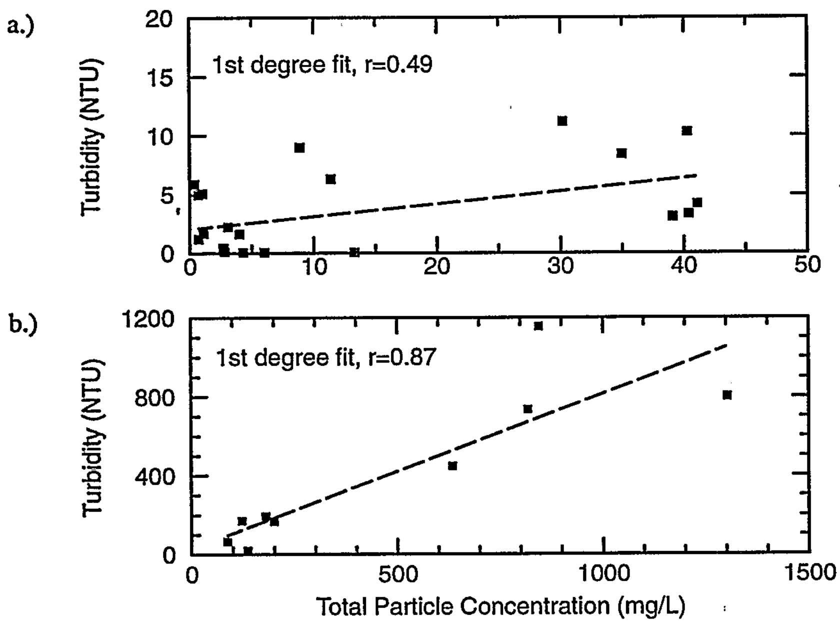

Figure 7. Plots of turbidity (NTU) versus total particle concentration (mg/L) for (a) samples containing less than 50 mg/L particles, and (b) samples containing more than 50 mg/L particles (with the exception of bailer at WISC-4).

level, analytical error may be ± 100% of the concentration (0.01 mg/L for all detected metals except arsenic). This variability must be kept in mind when interpreting the very low concentrations or comparing similar concentrations in the data set. Analytical results are contained in Appendix C. Estimates of the speciation of detected trace metals were made using the geochemical modeling program PHREEQE.

Of the observed metals, iron was the most likely to form colloids under the hydrochemical conditions present at the study sites, primarily as iron hydroxides. However, significant concentrations of dissolved ferrous iron may also have been present under the lower redox and pH conditions of the Washington site. If ferrous iron concentrations were high, oxidation and precipitation might occur in samples where oxygenation occurred during sample collection. If a significant fraction of this precipitate was removed during filtration, iron concentrations might be biased. Although manganese may form oxides in much the same way as iron, it is considerably more stable in aqueous form under oxic conditions than iron and is commonly present as the aqueous phases Mn^{2+} or $MnHCO_3^+$. Like other cations, aqueous manganese species are likely to sorb to particle surfaces and therefore might be impacted by filtration. Likewise, the aqueous form of nickel, Ni^{2+}, might react with particles although nickel carbonate precipitate ($NiCO_3$) might also be present, depending on pH and redox conditions. Nickel was targeted for analysis only at the Washington site. Barium, chromium, and arsenic were all expected to be primarily in the aqueous phase. Barium, as aqueous Ba^{2+}, is readily sorbed to metal oxides or hydroxides and so it might be expected to be impacted by filtration where particles are of this composition. Chromium was likely to be present as chromate (CrO_4^{2-}) under conditions in which it was detected and also may be associated with particles or colloids. Finally, arsenic was likely to be present primarily as arsenate ($H_2AsO_4^-$) at pH below 7 or arsenite ($HAsO_4^{2-}$) at pH above 7. The high potential for arsenate sorption on colloidal material was demonstrated by Puls and Powell (1992).

Because most samples contained suspended particles and colloids ranging from 0.03 μm to over 5.0 μm in size, it was expected that filtration would impact concentrations of those metals that either existed in the solid phase as particles greater than 0.4 μm, generally oxides of iron, or were associated with particles in this size range, which might include oxides, clays, minerals other than clays, or organics. Under these conditions, the greatest differences in concentration were expected to occur in samples collected by methods that produced the highest particle concentrations. These concentration differences were represented by their "filtration ratio," the ratio of unfiltered concentration to filtered concentration (Table 5). A filtration ratio of 1.00 indicates no difference between filtered and unfiltered concentrations, while a filtration ratio of zero (0) indicates that both filtered and unfiltered concentrations were below analytical detection levels. Filtration ratios denoted as undefined (und) indicate that an unfiltered concentration was detected but that the corresponding filtered concentration was below the analytical detection level. Filtration ratios found to be undefined are important because they indicate that all trace metals detected in unfiltered samples were removed during the filtration process.

An exploratory statistical analysis of the metals data set was conducted to identify major factors contributing to the variability observed in the concentrations. Iron, manganese, and arsenic were chosen for this analysis because they were detected by most devices in most wells. Concentrations reported as below the analytical detection level were set at the detection level for that particular analyte. In addition, a log transformation of the data set was made due to the skewed distribution and the large range in data values (two to three orders of magnitude). Well WISC-3 was not included in this analysis because only three of the four sampling devices were tested there.

The multivariate ANOVA indicated that the effect of sampling device was marginally significant and that the effects of filtration method and device–filtration interactions were not significant at the 0.05 level. These results reflect the highly variable hydrogeochemical conditions at each well and the fact that individual metals and metals species responded to filtration and device differently, depending on these unique conditions.

Univariate ANOVAs were subsequently conducted to investigate the response of individual metal ions to the experimental factors. These analyses incorporated the same seven wells as the multivariate ANOVA, unfiltered and 0.45-μm-filtered samples, all four sampling devices, and the metals iron, manganese, and arsenic. Univariate ANOVAs were also conducted for the barium data from WISC-2, WISC-4, NEV-1, and NEV-2 (barium was not analyzed in samples from the Washington site) and the nickel data from WASH-1, WASH-2, and WASH-3 (nickel was not analyzed in samples from the other two sites). The results showed a significant filtration effect for iron, manganese, and arsenic at the 0.025 significant level suggesting that concentrations of these ions showed consistent responses to 0.45-μm filtration compared to no filtration. In contrast, barium and nickel did not show significant responses to the effects of 0.45-μm filtration.

The effects of sampling device appeared significant for manganese and barium and marginally significant for iron at the 0.05 significance level. However, the results were biased by large effects at one or two wells and the other differences generally were not analytically significant, particularly for manganese. As a result, overall concentration trends (including both 0.45-μm-filtered and unfiltered samples) were not strong enough to indicate that the type of sampling device was an important contributor to concentration variation. Device–filtration interactions were significant at the 0.05 level for iron and barium, marginally significant at the 0.05 level for manganese, and not significant for arsenic and nickel. The effects of device–filtration interactions are clearly seen at wells where sampling devices produced high particle concentrations (Figures 8 through 12).

The greatest impacts of filtration on metals concentrations were observed at WISC-4 and WASH-1. Although filtration ratios were greatest for samples that contained the highest particle concentrations, virtually all samples were affected, regardless of sampling method. For samples with particle concentrations between 200 and 6970 mg/L (Bailer at WISC-4; BP, CP2, and Bailer at WASH-1), iron filtration ratios were 3400 for CP2 at WASH-1 and undefined for the other methods. Because over 95 percent of the particles in these samples were larger than 0.4 μm and therefore were removed during filtration, most of the solid iron hydroxide and any other associated iron species were also removed.

TABLE 5. FILTRATION RATIOS FOR METALS CONCENTRATIONS

ID	Cr	Fe	Mn	As	Ba	Ni
WISC-2						
CP1, 0.45 µm	0	5.00	und	0	1.00	–
CP1, 5.0 µm	0	1.25	und	0	1.00	–
BP, 0.45 µm	0	2.33	0	0	1.00	–
BP, 5.0 µm	0	3.50	0	0	1.00	–
CP2, 0.45 µm	0	0	0	0	1.00	–
CP2, 5.0 µm	0	5.50	0	0	1.00	–
Bail, 0.45 µm	0	340	11.0	0	3.08	–
WISC-3						
CP1, 0.45 µm	0	5.00	und	0	0.83	–
CP2, 0.45 µm	0	2.50	0	0	0.90	–
Bail, 0.45 µm	0	81.1	7.50	0	4.38	–
WISC-4						
CP1, 0.45 µm	0	100	2.00	0	1.10	–
BP, 0.45 µm	0	1.50	0.80	0	0.99	–
CP2, 0.45 µm	0	11.4	1.25	0	1.03	–
Bail, 0.45 µm	und	und	12.4	und	3.64	–
NEV-1						
CP1, 0.45 µm	0	1.00	1.01	0.93	1.08	–
CP1, 5.0 µm	0	1.00	0.99	1.00	1.04	–
BP, 0.45 µm	0	1.00	1.00	1.00	1.00	–
BP, 5.0 µm	0	1.00	1.00	1.09	1.00	–
CP2, 0.45 µm	und	1.25	1.00	1.07	1.04	–
CP2, 5.0 µm	1.00	1.00	1.00	1.07	1.04	–
Bail, 0.45 µm	0	34.5	1.07	0.94	1.88	–
Bail, 5.0 µm	0	19.7	1.08	1.07	1.81	–
NEV-2						
CP1, 0.45 µm	0	1.20	0.97	1.00	1.00	–
BP, 0.45 µm	0	1.00	0.98	1.00	1.04	–
CP2,0.45 µm	und	1.00	1.01	1.09	1.09	–
Bail, 0.45 µm	und	350	1.34	1.09	15.6	–
WASH-1						
CP1, 0.45 µm	und	81.0	1.88	1.40	–	4.00
BP, 0.45 µm	0	und	3.17	1.33	–	2.00
CP2, 0.45 µm	und	3400	15.0	3.00	–	18.0
Bail, 0.45 µm	und	und	12.9	3.33	–	und
WASH-2						
CP1, 0.45 µm	0	1.29	1.00	0	–	1.00
CP1, 5.0 µm	0	1.04	1.00	0	–	und
BP, 0.45 µm	0	1.16	1.00	0	–	0
CP2, 0.45 µm	0	1.21	1.00	0	–	0
Bail, 0.45 µm	und	16.4	4.75	2.00	–	und
WASH-3						
CP1, 0.45 µm	0	1.01	1.01	0.88	–	1.33
CP1, 5.0 µm	0	1.00	1.01	0.88	–	1.00
BP, 0.45 µm	0	1.03	1.03	0.88	–	1.00
BP, 5.0 µm	0	1.03	1.04	0.88	–	1.00
CP2, 0.45 µm	0	1.16	1.13	1.00	–	1.00
CP2, 5.0 µm	0	1.05	1.05	1.00	–	1.00
Bail, 0.45 µm	0	1.01	1.01	1.20	–	1.00
Bail, 5.0 µm	0	1.02	1.02	1.00	–	0.80

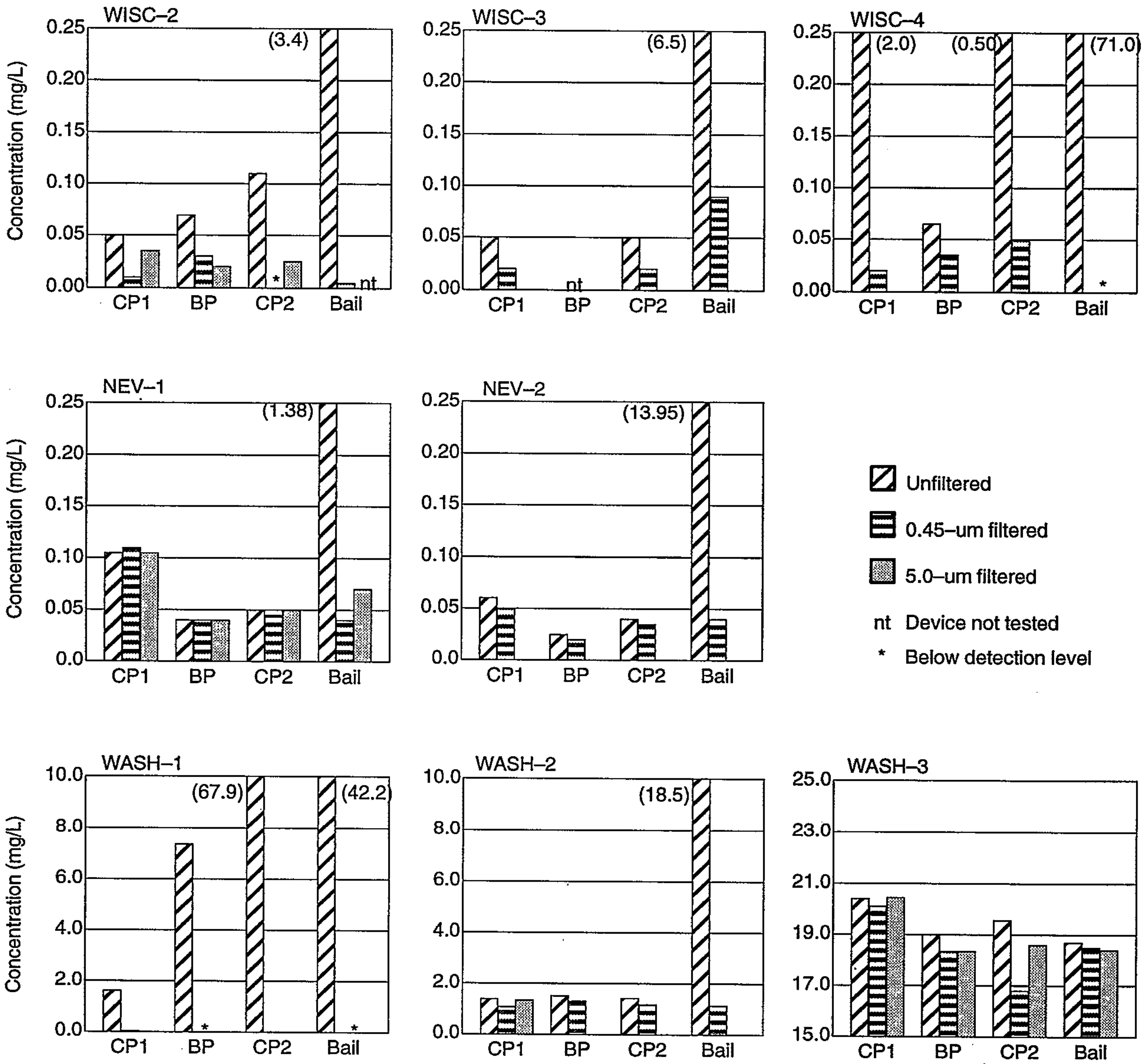

Figure 8. Iron concentrations

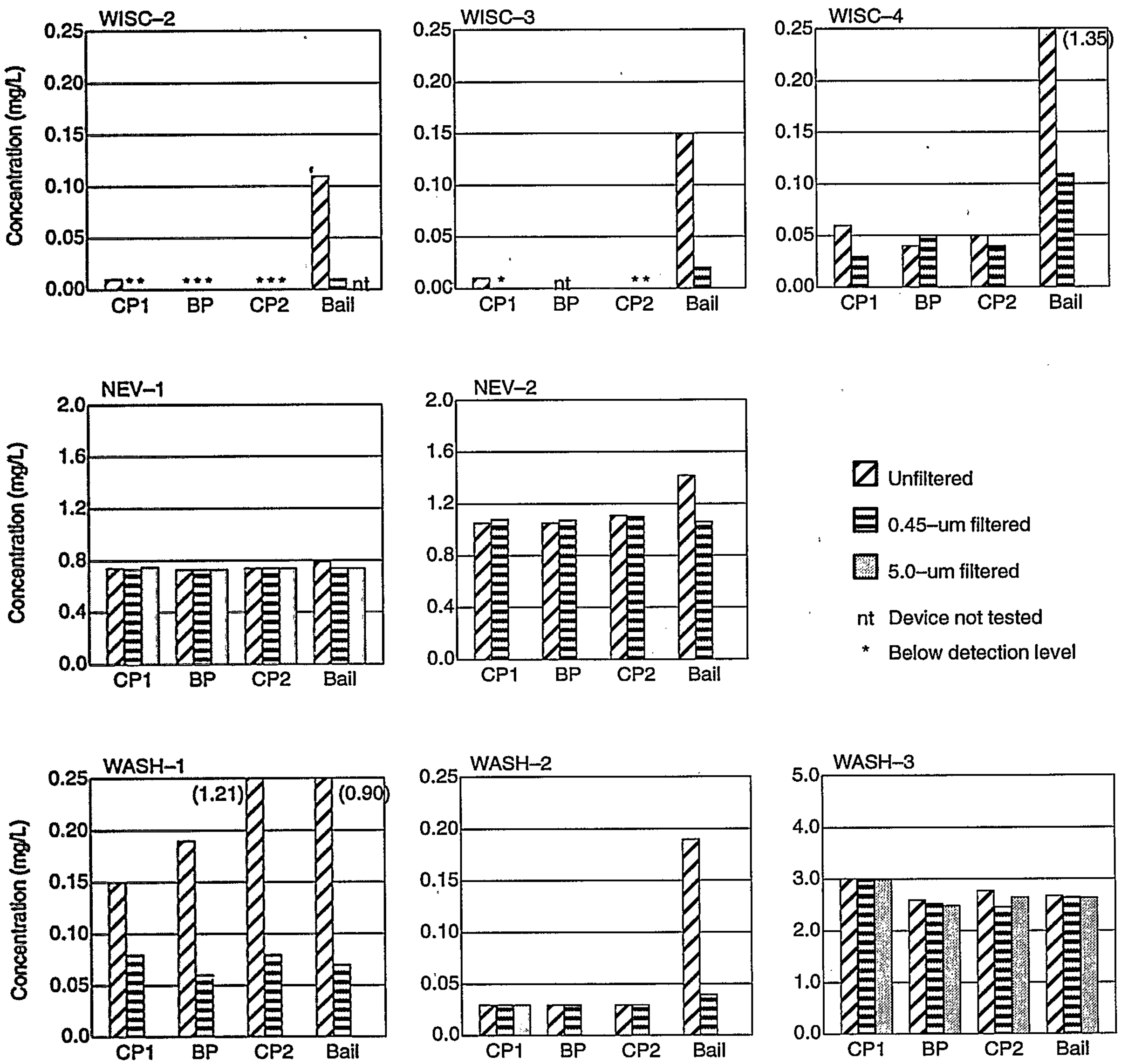

Figure 9. Manganese concentrations

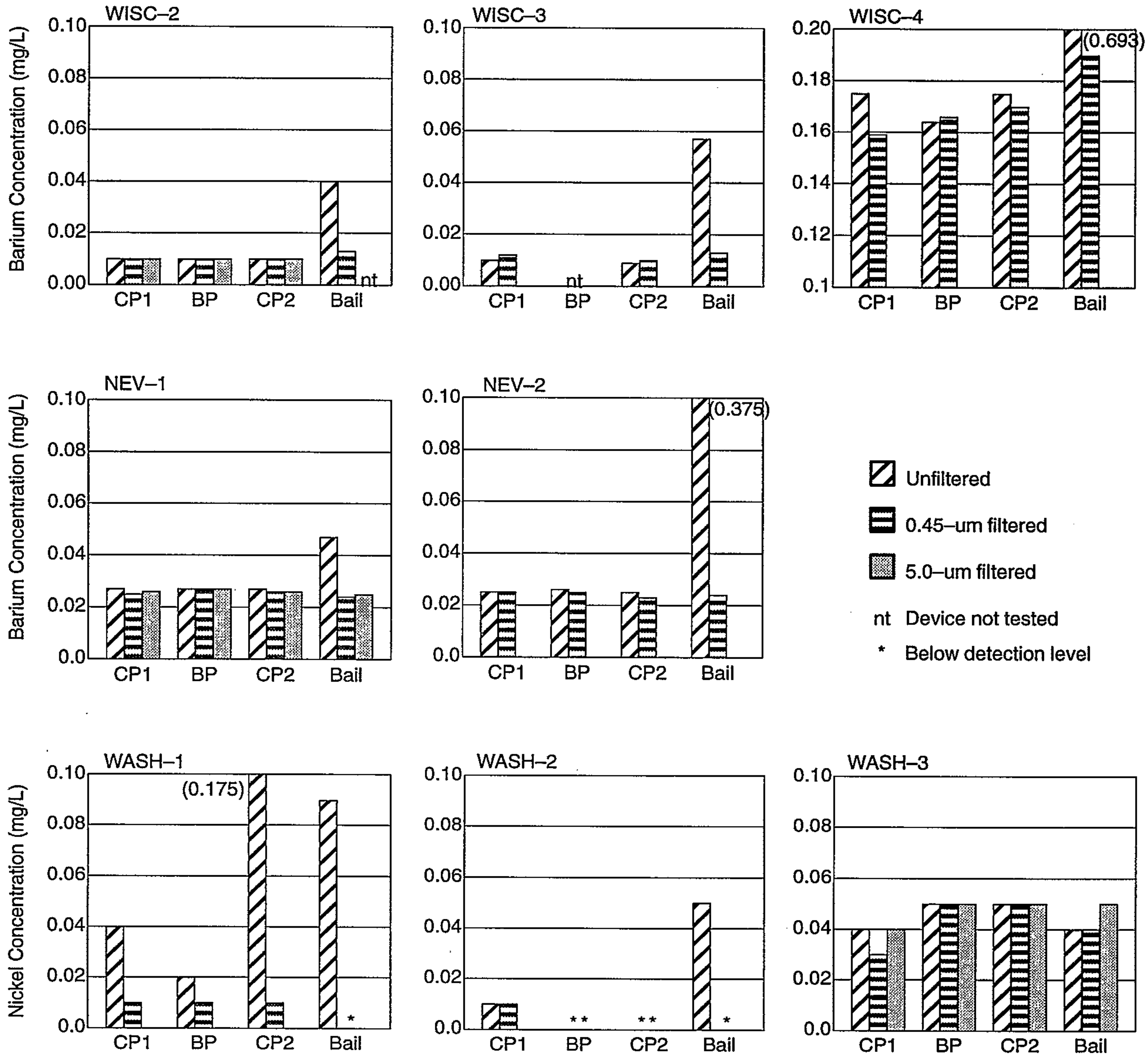

Figure 10. Barium concentrations for Wisconsin and Nevada sites, nickel concentrations for Washington site (barium not analyzed at Washington site, nickel not analyzed at Wisconsin and Nevada sites).

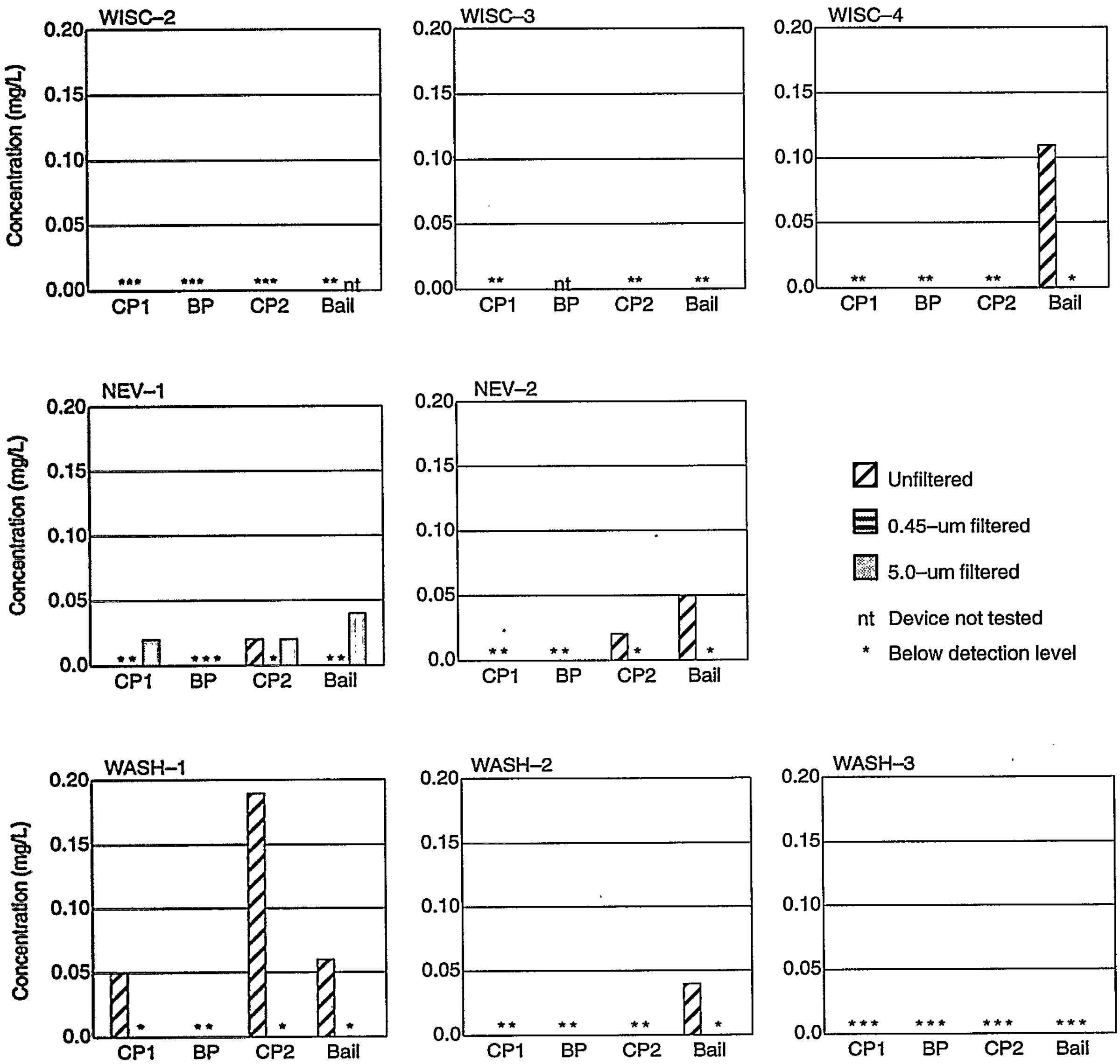

Figure 11. Chromium concentrations

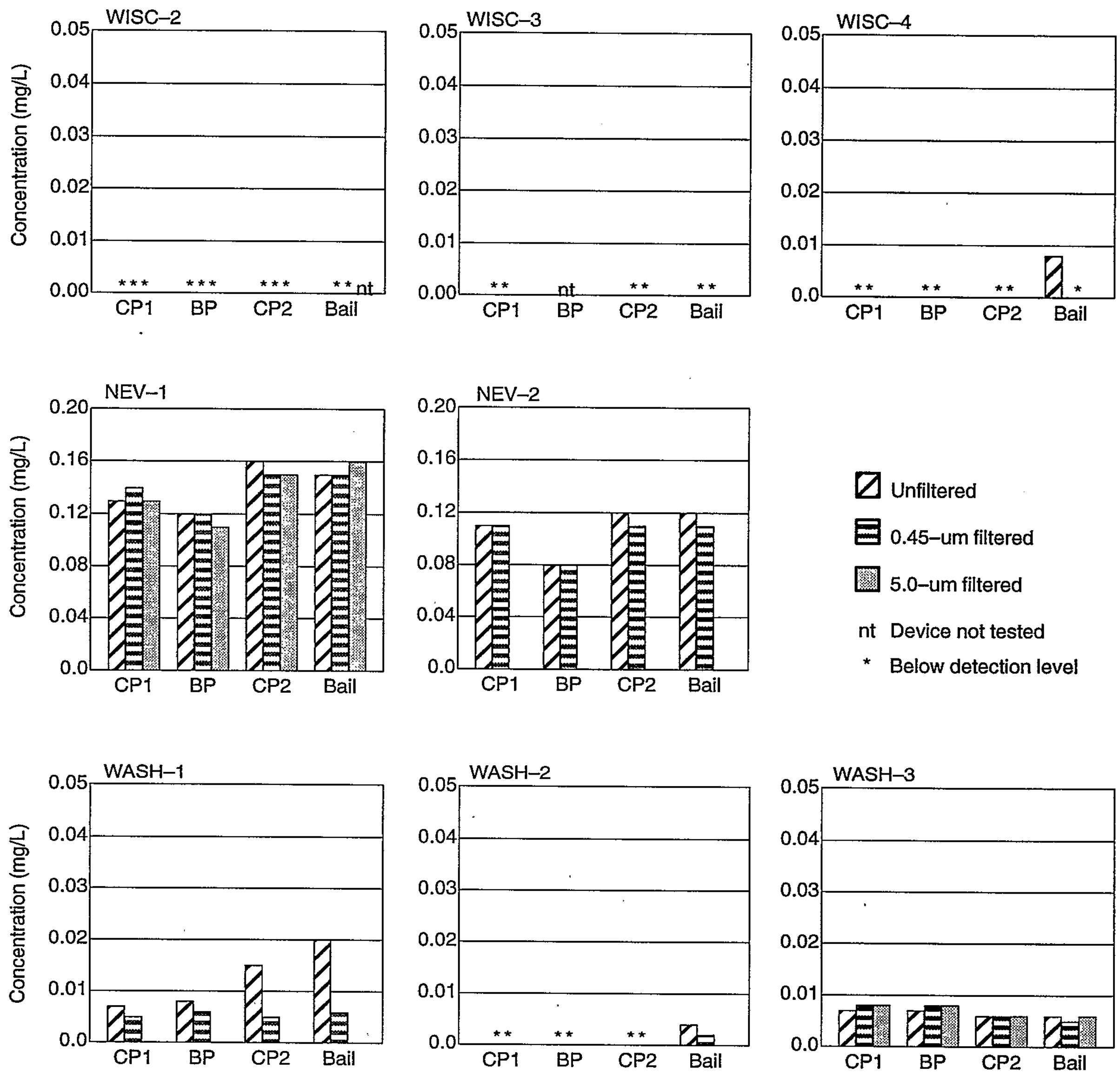

Figure 12. Arsenic concentrations

Similar relationships were observed for other metals at these wells, although to a much lesser degree. For example, the manganese filtration ratio for samples bailed from WISC-4 was 12.4, while the largest ratio for pumped samples was 2.00 (CP1). At WASH-1, the manganese filtration ratio ranged from 1.88 (CP1) to 15.0 (CP2) and unfiltered manganese concentrations correlated to the total particle concentrations. At WISC-4, barium had a filtration ratio of 3.64 for bailed samples, while pumps produced ratios of 0.99 to 1.10. Arsenic was detected only in the unfiltered bailed sample at WISC-4. Samples with the highest particle concentrations at WASH-1 showed arsenic filtration ratios of around 3.00 while samples with low particle concentrations had arsenic filtration ratios less than 1.40 (CP1 and BP). Chromium was detected only in unfiltered samples that contained very high particle concentrations. These results suggest that significant fractions of manganese, barium, arsenic, and chromium species were associated with particles that were mobilized during the more vigorous sampling events and that filtration either removed the metals species entirely or removed significant quantities with the particles. Note, however, that sampling methods that caused minimal disturbance to the sampling zone in these turbid wells also generally produced either filtration ratios near 1.00 or resulted in nondetection of the metal.

Despite the relationships evident for samples with high total particle concentrations, samples with lower total particle concentrations did not necessarily produce filtration ratios near 1.00. For example, total particle concentrations at WISC-2 and WISC-3 ranged between 0.7 and 2.8 mg/L in the pumped samples and 122 and 180 mg/L in the bailed samples. Iron filtration ratios ranged from 2.33 to 5.00 (with one undefined value) for the 0.45–μm filtered pumped samples and from 81.1 to 340, for the bailed samples. Similarly, 5.0–μm filtration ratios for the pumps ranged from 1.25 to 5.50. Because 14 to 57 percent of the particles in the pumped samples were smaller than 0.4 μm, it appears that an important fraction of the iron may be in colloidal form or associated with colloids that passed through the 0.45–μm filters to become part of the analysis. Although the absolute differences in iron concentration evident at WISC-2 and WISC-3 are significant, they actually represent only relatively small differences in concentration, particularly for the pumped samples, where concentrations differed by as little as 30 μg/L. Variation in iron results at these low concentrations are likely the result of artifacts of sample handling and analysis which are commonly higher for iron analyses.

The relationship between relatively high particle concentrations and measurable differences between filtered and unfiltered concentrations of the other metals was also evident at WISC-2 and WISC-3. For example, manganese detected in the bailed samples exhibited filtration ratios of 11.0 and 7.5, respectively. Likewise, barium, which was detected in pumped samples with filtration ratios of 0.83 to 1.00, exhibited filtration ratios of 3.08 and 4.38, respectively, for the bailed samples. Arsenic and chromium were not detected in any samples from these wells.

Samples from WASH-2, which contained particle concentrations between 8.9 mg/L (CP1) and 818 mg/L (bailer), exhibited much lower iron filtration ratios. The iron filtration ratio was approximately 16 for bailed samples and ranged from 1.04 to 1.29 for pumped samples. Lower particle concentrations in the pumped samples were accompanied by a generally higher fraction of sub-0.4-μm particles, approximately 75 percent for the BP and CP2. It appears that the lower total particle concentrations and greater proportion of particles passing through the 0.4–μm filters (for the pumped samples only) contributed to less pronounced concentration differences between filtration method than observed at the WISC wells and WASH-1. The pattern of response of the other metals was similar to that observed at the wells discussed previously in that filtration ratios were the greatest, or undefined, for the bailed samples, while the pumped samples had filtration ratios of 1.00 or did not contain measurable concentrations.

Iron concentrations in unfiltered and filtered samples pumped from NEV-1 and NEV-2 were virtually indistinguishable (filtration ratios between 1.00 and 1.25, inclusive; 5.0 μm filtration ratios of 1.00), although concentrations of sub-0.4-μm particles in the pumped samples varied from 27 to 90 percent (0.8 to 11.8 mg/L) of total particles. This suggests that the solid $Fe(OH)_3$ may be associated with particles of a fairly constant fraction of sub-0.4 μm particles, or that the iron is actually present in dissolved form. In contrast to the pumped samples, iron filtration ratios of bailed samples were much higher: 34.5 and 350 for the 0.45–μm filters and 19.7 for the 5.0–μm filter. As was observed for most other bailed samples, over 85 percent of particles in the samples bailed from NEV-1 and NEV-2 were larger than 0.4 μm and were removed from the samples by filtration, thereby removing the majority of the iron oxide particles mobilized or formed during the bailing process. Because the 5.0–μm filters allowed slightly more particles to pass into the NEV-1 samples than the 0.45–μm filters, the 5.0-μm-filtered samples exhibited slightly higher concentrations. The 0.45-μm and 5.0-μm filtration ratios for manganese, barium, and arsenic in pumped samples (and arsenic for bailed samples) were all within the range of 0.93 to 1.09, reflecting the predominance of the aqueous phases or association with particles smaller than 0.4 μm. In contrast, bailed samples showed manganese and barium filtration ratios of 1.07 to 15.6, reflecting association of these metals with the greater concentrations of particles mobilized during the bailing process and were then removed during filtration.

Iron filtration ratios at WASH-3 were also very low, between 1.00 and 1.16, but unlike all other wells in the study the ratio was also low for the bailed samples. Also, unlike all the other wells in the study, total particle concentrations for all devices were similar, ranging from 39.1 to 41.1 mg/L. Chemical equilibrium modeling suggests that an important fraction of the iron at this well may be dissolved ferrous iron which would be relatively unaffected by filtration. Furthermore, analysis of the grain-size distribution of samples from WASH-3 revealed that all methods produced less than 5 percent of total particle concentration in the 0.03- to 0.45-μm size range. As a result, either the iron is present primarily as a dissolved species or, if the iron is colloidal, the particles are smaller than 0.03 μm. The higher DO concentrations of the bailed samples with respect to the pumped samples did not appear to impact filtration results, suggesting that little ferrous iron was available to precipitate or that the precipitate was formed of particles smaller than 0.45 μm.

Filtration ratios for manganese, nickel, and arsenic at WASH-3 ranged from 0.80 to 1.33 for all devices while chromium was not detected. Equilibrium modeling suggested that these metals were present primarily as aqueous species and because filtration had little impact on their concentrations, there appears to be little association with sub-0.4 μm particles. The importance of understanding the speciation of metals with regard to sample filtration is clearly illustrated for the case of nickel at WASH-1 and WASH-3 (Figure 10). At WASH-3, where equilibrium calculations suggest that the aqueous phase Ni^{2+} and possibly the aqueous phase nickel bicarbonate ($NiHCO_3^{+}$) are thought to predominate and total particle concentrations were roughly equal for all sampling methods, neither 0.45-μm nor 5.0-μm filtration had a significant effect on nickel concentrations. By contrast, at WASH-1 the solid phase nickel carbonate is the predominant nickel species indicating that nickel carbonate may have precipitated out of solution and accumulated in sediments near the well. The action of sample collection may have mobilized and incorporated significant concentrations of this species in the unfiltered samples, particularly in those samples with high particle concentrations. Filtration of the samples removed the bulk of the nickel carbonate and the remaining concentration represents nickel carbonate particles smaller than 0.4 μm in size or dissolved. What cannot be determined from these data, however, is whether an important fraction of the nickel solid phase is mobile within the ground-water system.

As discussed above, results of univariate ANOVAs for individual metals in the unfiltered and 0.45-μm filtered samples (taken as a group) suggested that 0.45-μm filtration was a significant effect for certain metals, namely iron, manganese, and arsenic. However, results from individual wells clearly show that bailed samples, which contained the highest particle concentrations, were the most important contributor to this filtration effect. Univariate ANOVAs for these same three metals collected with the pumps alone indicated that significant differences existed only for iron. In other words, no statistically significant differences existed in concentrations of manganese, arsenic, nickel, and barium between unfiltered and 0.45-μm filtered samples collected at the same well by the bladder pump and the centrifugal pump at the two rates. It appears that the significant differences in iron concentrations result from the close association of iron with particles entrained in samples, a major fraction of which were removed by 0.45-μm filtration (particularly in the most turbid samples). When the ANOVA was expanded to include just bailed samples that were 0.45-μm filtered, iron remained the only metal with concentrations significantly different between device–filter combinations. This occurrence suggests that for most of the metals analyzed (and for which there were sufficient data), 0.45-μm filtration resulted in statistically indistinguishable concentrations in samples from different devices in the same well.

IMPACTS OF SAMPLING DEVICE ON METALS CONCENTRATIONS

Relationships of trace metal concentrations to sampling devices were heavily dependent on the phase in which the species was present and the potential for association with particles of that species. For example, unfiltered concentrations of the predominantly aqueous arsenic showed very little variation between devices except in samples that contained extremely high particle concentrations (primarily bailed samples). Filtration had little effect on concentrations except in the most turbid samples, so the filtered samples also showed very little variation between devices. In the turbid samples, primarily at WISC-4 and WASH-1, concentrations in unfiltered samples were slightly higher than in filtered samples but filtration removed the fraction associated with the larger particles and produced essentially equal concentrations for all devices at individual wells. Likewise, where nickel was present primarily in aqueous form (WASH-3), all devices produced similar concentrations in both filtered and unfiltered samples. For these constituents, filtration generally did not impact relative concentrations between devices with the exception of those devices that produced samples with very high particle concentrations.

Manganese and barium, both of which were also primarily present as aqueous species, showed a closer relation between device type and unfiltered concentrations than arsenic and nickel. For manganese and barium, the bailers usually produced the highest unfiltered concentrations, up to 15 times higher than the unfiltered pumped samples. Concentrations in the unfiltered pumped samples were essentially equal except in the more turbid samples, where slightly more variation was observed, and at WASH-3, where CP1 produced manganese concentrations that were slightly higher than the other devices. In most cases, the filtered concentrations of all four devices were essentially equal to each other and equal to the unfiltered pumped samples. Exceptions occurred at WASH-1 where the high particle concentrations produced by most devices were accompanied by high unfiltered manganese concentrations relative to filtered concentrations. The higher unfiltered concentrations most often observed in bailed samples suggest a direct relationship to the higher particle concentrations produced by these devices and, as a result, are unlikely to represent the potential for mobility in the ground-water environment. As with aqueous arsenic and nickel, however, filtration removed the fraction of these constituents associated with particles larger than 0.45 μm, resulting in relatively little variation in unfiltered concentrations between devices.

Aqueous chromate was usually present in unfiltered bailed samples but rarely detected in unfiltered samples from other devices. The response to filtration was similar to the metals discussed above but to a greater extreme. In this case, filtration removed all chromium detected in the unfiltered samples for all devices and wells (with the exception of low concentrations detected at NEV-1), indicating that virtually all of the chromate was associated with particles larger than 0.45 μm. The result was that all four sampling methods produced essentially "equal" concentrations of chromium in filtered samples, that is, below detection.

As discussed previously, iron generally exhibited the highest variability in both filtered and unfiltered samples, reflecting complicated relationships to redox conditions and particle concentrations. Despite this variability, unfiltered iron concentrations were highest in samples collected by the device that produced the most turbid samples, which was the bailer in six of the eight wells. In the less-turbid wells, unfiltered bailed samples contained iron concentrations up to 300 times higher than pumped samples, while in the most turbid wells concentrations in unfiltered bailed samples were sometimes over 1000 times higher than in pumped samples. As noted previously, filtration of pumped samples from the less turbid wells resulted in slightly lower concentrations than in unfiltered samples but in most cases not significantly because concentrations were near analytical detection levels. In turbid samples, filtration significantly reduced concentrations in pumped samples as a result of removal of iron particles. Filtration of bailed samples resulted in iron concentrations that usually fell within the range present in the pumped samples, although all iron was removed in the most turbid samples. Variability in both unfiltered and filtered pumped samples caused by particle concentrations and size distribution was sufficient to mask any significant response pattern related to pump type, although CP1 showed slightly higher concentrations than the other pumps at NEV-1, NEV-2, and WASH-3. These higher concentrations appear to be unrelated to particle concentrations and may result from this pump being the first to sample each well at the NEV and WASH sites. Therefore, as with the other metals, any differences in concentrations produced by different pumps and discharge rates were considered insignificant.

Impacts of filtration on metals present primarily as solid species can also be seen for nickel at WASH-1. Nickel concentrations in the unfiltered samples show a relationship to particle concentrations that suggests the presence of nickel carbonate precipitated out in the sediments of the sampling zone. A significant fraction of nickel was then removed during filtration and the fraction of these particles smaller than 0.45 µm was relatively uniform for the pumps as evidenced by the filtered concentrations. These concentrations were low for the pumps (from below detection up to 0.05 mg/L) but were all below detection for the bailer.

Univariate ANOVAs of the unfiltered concentrations of iron, manganese, and arsenic with the four sampling devices at seven wells confirmed the overall trends discussed above. In particular, significant differences were found to exist in the unfiltered concentrations produced by the different sampling devices for all three of these metals. Those samples containing the highest particle concentrations also had unfiltered metals concentrations that were significantly higher than the other samples. In most cases, the bailer produced samples with the highest particle concentrations and, therefore, produced significantly higher metals concentrations in unfiltered samples. In contrast, no significant differences existed between concentrations for these three metals in the 0.45-µm-filtered samples, suggesting that filtration removed nonrepresentative particle loads from the turbid samples and caused samples from all four devices to be essentially indistinguishable.

IMPACTS ON CONCENTRATIONS OF MAJOR IONS

Methods of sampling and filtration had little impact on the concentrations of major anions with most differences less than five percent, even for those samples with very high particle concentrations (Appendix C). Relative differences in concentration greater than five percent usually occurred near analytical detection levels where errors are considered to be highest. Univariate ANOVAs for individual anions showed no significant effect of device, filtration method, or device–filtration interactions, indicating that, taken as a group, anion concentrations were not significantly impacted by these factors. Furthermore, associations between anions and particles appeared minimal because filtration of samples with high particle concentrations did not cause large differences in anion concentrations.

An exception to this overall trend was observed at WISC-2 where 0.45–µm filtration caused analytically significant differences in anion concentrations. In most samples from this well, unfiltered concentrations were usually over 10 percent higher than 0.45-µm-filtered concentrations. Differences exhibited by the divalent anion carbonate (CO_3^{2-}) and sulfate (SO_4^{2-}) were larger than for the monovalent anion chloride (Cl^-), bicarbonate (HCO_3^-), and nitrate (NO_3^-), demonstrating the greater potential for reactions of these divalent anions with particle surfaces. The differences in concentrations observed at WISC-2, though small, appear to be related to removal by filtration of an important fraction of positively-charged particles with which certain anionic species were associated. This relationship between anions and particles was not observed at the other wells.

Concentrations of major cations were more affected by particle concentrations than major anions due to their positive charge and the generally negative surface charge of many particles in the size range investigated in this study. Univariate ANOVAs for individual cations indicated that device and filtration effects and interactions were all significant, although not all effects were significant for all cations. As expected, samples containing less than 50 mg/L particles (primarily pumped samples) showed small differences between filtered and unfiltered samples and between devices. In these less turbid samples, differences were always less than 10 percent and most were less than 5 percent. As a result, the pumps generally showed little variation in cation concentrations, both between devices and between filtration methods. Bailers seldom produced samples with less than 50 mg/L particles.

Alternatively, samples containing in excess of 50 mg/L particles showed significant differences in cation concentrations between filtered and unfiltered samples. Significant differences were also evident between unfiltered cation concentrations in these samples and those in unfiltered samples from devices that produced low particle concentrations. The monovalent major cations potassium (K^+) and sodium (Na^+) showed the least variation, often less than 5 percent while the divalent major cations calcium (Ca^{2+}) and magnesium (Mg^{2+}) showed the most variation. Filtration caused unfiltered magnesium concentrations to be up to 3 times higher than 0.45-µm-filtered concentrations, and unfiltered calcium concentrations to be up to 4 times higher than 0.45-µm-filtered concentrations. These differences were most likely related to the association of these positively-charged ions with high concentrations of particles having primarily negative surface charge and the effect of removing significant concentrations of these particles by sample filtration.

Under conditions where all analytes are truly dissolved, the sum of positive and negative charges in filtered and unfiltered samples (from a single sampling event) should balance and therefore differences in concentrations of cations between filtered and unfiltered samples should not exceed differences in anions. As a result, there should only be minimal differences in the overall variability of anion and cation concentrations across filtration methods. The fact that cations exhibited higher variability than anions in this study is primarily related to significant particle concentrations in many of the unfiltered samples. These particles were a likely source of cations, particularly calcium and magnesium, released into solution during sample digestion and not naturally balanced by dissolved anions. Furthermore, because most of the particles in the turbid samples were larger than 5.0 µm and therefore unlikely to be mobile in the ground-water environment, these higher cation concentrations are clearly unrepresentative of mobile constituents.

Univariate ANOVAs for organic carbon indicated no significant effect for filtration but a significant effect for device, with the bailer significantly different from the other devices. Organic carbon concentrations were generally highest in the bailed samples because bailing entrained more particles, and in some wells (particularly WISC-4 and WASH-2) organic carbon was an important component of the particle load. The trend observed at some wells of slightly higher organic carbon concentrations in 0.45-µm-filtered samples than in the associated unfiltered samples represents traces of glycerol (used to maintain structural integrity) and organic membrane wetting agents that were washed off the filters into the sample container. This effect was not observed for the 5.0–µm filters.

Laboratory measurements of pH, although not representative of absolute field conditions, indicate that bailed samples were subjected to greater degassing than pumped samples. Bailed samples exhibited overall significantly higher pH values relative to pumped samples based on univariate ANOVAs. Filtration did not have a significant effect on laboratory pH measurements.

PRACTICAL CONSIDERATIONS

Several practical considerations should be evaluated when designing and implementing a program for sampling trace metals in ground water. First, turbidity measurements offer a useful indicator of particle concentrations in ground water, thereby providing important information about the effectiveness of monitoring well purging and the relative concentration of particles at different wells. Turbidity is relatively easy to measure in the field and the turbidimeter calibration is generally highly stable. In addition, the use of a flow-through cell allows nearly continuous monitoring during pumping and greatly reduces variability in the measurements.

Sample collection at low to moderate discharge rates (up to 1000 mL/min) requires a sampling device capable of providing stable discharge at these rates over relatively long periods of time. In this study, the bladder pump met these criteria with few adjustments needed to ensure continuous discharge at the desired rate. The bladder pump also performed well under the variable head conditions encountered at two low-yield wells. In contrast, the submersible centrifugal pump was not generally capable of meeting these criteria, especially under low-yield conditions. The inability to maintain constant discharge was apparently related to head conditions during purging and sampling; as drawdown increased with pumping, total head on the pump system increased and pump discharge was reduced. At low discharge rates, it appeared that very little increase in total head was required to cause a total loss of discharge.

This situation was addressed by frequent measurements of the discharge rate and adjustments of the pump speed as necessary. However, this approach required the field personnel's near-constant attention and prevented them from carrying out other tasks related to the sampling event. If this type of device is under consideration for low-discharge-rate sampling, hydraulic conditions should be carefully evaluated to determine whether a low-yield well will be encountered. Finally, although bailers are theoretically capable of producing low "discharge" rates, they are very difficult and impractical to operate in this manner. Even with very gentle use, the surging action generated by a bailer as it is raised and lowered through the water column is more than enough to suspend and entrain normally immobile particles.

Although purging and sampling at low pump speeds may reduce purging volumes and produce less disturbed samples, the time required to complete purging may be considerably longer. In this study, purging times for the pumps were up to four times higher than for the bailer (Table A–1) although it must be pointed out that equipment problems with the centrifugal pump significantly increased purging times at several wells. Also, several purging criteria were not met when purging with the bailer due to agitation of the sampling zone by the action of the bailer in the well bore. In several of the wells, purging times for the pumps were lower or no more than 50% higher than for the bailer. Purging times associated with low–rate pumping might be minimized through the use of dedicated equipment that would eliminate the initial disturbance of the sampling zone and water column observed during the emplacement of a sampling device in the well (Puls et al., 1991; Kearle et al., 1992). Dedication of sampling pumps to individual wells may also allow simultaneous purging of several wells, as suggested by Backhus (1993), significantly reducing the overall time required to purge a network of wells. However, dedicated systems require considerable up front capital costs that may limit their widespread use.

On the other hand, dedication of sampling equipment may also save time and other resources in many aspects of the sampling process. For example, the time and effort required for decontamination of portable sampling equipment is completely eliminated, as are the time to collect samples and the cost of analyzing equipment rinsate blanks. Also, the quantity of equipment needing transport from well to well is reduced. Although not tested in this study, positive displacement pumps other than bladder pumps may be equally capable of providing representative samples of trace metals and other constituents and are often available with more portable power sources. For example, submersible gear pumps and progressing cavity pumps are both powered by 12–volt D.C. which can easily be supplied by a deep-cycle marine battery. This type of power system is considerably more portable than the generator necessary for the submersible centrifugal pump or the nitrogen cylinder or generator necessary for the bladder pump. Peristaltic pumps may also be useful under conditions where depth to water is less than approximately 6 meters from ground surface, although degassing may be a problem.

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APPENDIX A
Summary of Indicator Parameter Measurements and Purging Data

TABLE A–1. VALUES OF FIELD PARAMETERS DURING PURGING

Well ID/Device	Vol (L)	Time (min)	DO (mg/L)	T (°C)	pH	EC (µS)	Turb. (NTU)
WISC–2							
CP1 (Q=370 mL/min)	2.45	5	3	10.1	7.98	259	31.5
	2.75	8	1.6	10.2	8.42	259	28.8
	3.95	11	1.3	10.1	8.7	228	19.5
	5.15	14	0.9	10.6	8.82	221	15.7
	6.35	17	0.8	11.8	8.86	212	13.5
	7.55	20	0.7	12.3	8.88	213	12.2
	9.55	25	0.6	12.1	8.89	209	9.5
	11.55	30	0.5	12.3	8.91	208	8
	13.55	35	0.5	12.5	8.92	209	7.5
	15.55	40	0.5	12.7	8.91	209	6.5
	17.55	45	0.4	12.9	8.92	204	6.4
	19.25	50	0.4	13.2	8.92	204	6
	20.95	55	0.4	13.2	8.91	204	5.8
	22.65	60	0.3	13.2	8.91	205	5.5
	24.35	65	0.3	13.6	8.91	205	5
BP (Q=500 mL/min)	4.8	6	4.8	10	7.32	289	6.2
	5.4	8	1.1	9.8	8.35	282	4.9
	6	10	0.8	9.7	8.04	260	4.5
	6.6	12	0.7	9.6	8.91	235	4.2
	7.2	14	0.7	9.6	9.02	228	3.5
	8.2	16	0.7	9.6	9.07	223	2.8
	9.2	18	0.6	9.6	9.04	220	2.3
	10.2	20	0.5	9.5	9.1	218	3
	11.2	22	0.5	9.4	9.1	218	2.4
	12.2	24	0.4	9.4	9.1	220	1.8
	13.2	26	0.4	9.4	9.1	218	1.8
	15.2	30	0.3	9.4	9.1	217	1.6
	17.7	35	0.3	9.4	9.1	217	1.3
	20.2	40	0.3	9.4	9.1	215	1.3
	22.7	45	0.3	9.4	9.09	214	1.3
	25.2	50	0.2	9.4	9.1	214	1.2
CP2(Q=940mL/min)	3	3	1.5	10.7	8.17	243	2.5
	5	5	0.6	11	8.76	215	2.45
	6.8	7	0.5	11.4	8.93	211	1.93
	8.7	9	0.4	11.3	8.96	210	1.51
	10.5	11	0.4	11.4	8.98	208	1.87
	12.4	13	0.3	11.4	9	207	1.42
	14.2	15	0.3	11.5	9	207	2.25
	16	17	0.2	11.6	9	207	3.06
	17.9	19	0.2	11.9	9	202	1.82
	19.7	21	0.2	11.8	9	201	1.32
	21.6	23	0.2	11.5	9.01	203	1.92
	23.4	25	0.2	11.4	9.01	203	1.66
Bail	65.3	33	3.9	12.2	8.20	212	170

continued

TABLE A–1. VALUES OF FIELD PARAMETERS DURING PURGING

Well ID/Device	Vol (L)	Time (min)	DO (mg/L)	T (°C)	pH	EC (μS)	Turb. (NTU)
WISC–3							
CP1 (Q=320 mL/min)	0.38	1	3.7	8.0	7.63	311	3.28
	1.14	3	1.8	8.5	8.21	248	2.71
	1.90	5	1.4	8.5	8.53	240	2.51
	2.80	6	1.1	10.2	8.93	209	5.11
	3.06	7	1.1	10.1	8.94	209	4.88
	3.58	9	1.1	10.1	8.96	208	5.31
	4.62	13	0.7	10.2	8.98	209	5.56
	5.18	15	0.7	11.0	8.98	207	5.41
	5.94	17	0.6	11.8	8.98	209	3.92
	6.74	19	0.5	11.9	8.98	202	2.91
	7.74	21	0.5	11.9	8.98	202	2.40
	8.74	23	0.4	11.9	8.98	201	1.83
	9.34	25	0.4	11.9	8.98	200	1.89
	9.94	27	0.4	12.0	8.98	201	1.51
	10.9	29	0.3	12.0	8.98	200	1.31
	11.6	31	0.3	12.0	8.98	200	1.11
	12.2	33	0.3	11.5	8.99	201	2.61
	12.9	35	0.4	11.5	8.99	201	1.73
	14.4	37	0.3	11.3	8.99	199	1.31
	15.7	39	0.3	11.4	8.98	199	1.21
	16.3	41	0.3	11.8	8.99	194	0.53
	16.9	43	0.3	11.9	8.99	193	0.51
	17.5	45	0.3	11.3	8.99	194	0.34
	18.1	47	0.3	11.5	8.99	201	0.72
	18.7	49	0.3	11.5	8.99	202	2.98
	20.2	51	0.3	11.4	8.99	202	0.51
	20.9	53	0.2	10.8	9.00	198	0.11
CP2 (Q=900 mL/min)	4.0	4	3.8	10.2	9.56	218	16.28
	5.0	5	3.1	10.0	9.22	213	10.38
	7.0	7	0.7	10.2	8.98	215	35.5
	9.0	9	0.4	10.9	8.96	212	43.2
	11.0	11	0.4	10.9	8.98	209	20.7
	14.3	15	0.3	11.1	8.99	207	10.5
	16.3	17	0.3	11.8	8.99	205	10.2
	18.1	19	0.2	11.6	9.00	209	9.2
	19.9	21	0.2	11.4	9.01	203	6.4
	23.5	25	0.2	11.3	9.00	205	4.7
	25.3	27	0.2	11.3	9.00	205	4.4
	27.1	29	0.1	11.4	9.00	203	4.2
	28.9	31	0.1	11.3	9.00	202	5.7
	30.7	33	0.1	11.3	9.00	202	4.7
	32.5	35	0.1	11.4	9.00	201	6.1
	34.3	37	0.1	11.4	9.00	200	5.2
	36.1	39	0.1	11.5	9.00	202	4.7
	37.9	41	0.1	11.4	9.00	201	3.7
	39.7	43	0.1	11.5	9.00	198	5.1
Bail	56.8	28	–	9.8	9.00	240	195

continued

TABLE A–1. VALUES OF FIELD PARAMETERS DURING PURGING

Well ID/Device	Vol (L)	Time (min)	DO (mg/L)	T (°C)	pH	EC (µS)	Turb. (NTU)
WISC–4							
CP1 (Q–330 mL/min)	1.5	5	4.5	13.2	6.30	258	0.12
	2.4	8	4.5	13.8	4.66	171	0.15
	3.0	10	5.1	14.0	5.37	782	3.70
	3.6	12	5.4	13.9	7.04	1248	3.12
	4.5	15	5.1	13.4	7.15	1409	3.80
	6.9	20	4.6	13.5	7.15	1428	11.1
	8.8	25	4.2	13.9	7.14	1406	23.5
	10.2	30	4.8	14.2	7.07	1435	27.3
	11.8	35	4.3	14.8	7.07	1430	18.3
	13.4	40	4.1	15.4	7.09	1459	23.8
	15.0	45	3.7	15.6	7.06	1469	52
	16.6	50	3.4	15.6	7.08	1459	41.9
	18.2	55	3.2	15.2	7.08	1449	39.7
	19.8	60	2.7	14.9	7.07	1449	36.0
	21.4	65	1.3	15.4	7.08	1459	22.1
	23.0	70	1.1	15.0	7.09	1430	12.0
	24.6	75	1.0	14.3	7.09	1435	8.0
	26.2	80	0.9	13.6	7.09	1448	7.3
	28.13	86	1.2	12.9	7.09	1422	10.5
	29.12	89	1.2	13.0	7.10	1428	21.7
BP (Q=510 mL/min)	1.48	2	5.8	10.0	7.08	1351	14.5
	2.96	4	3.6	10.9	7.16	1418	41.5
	4.44	6	2.9	11.1	7.16	1439	36.4
	5.58	8	2.3	11.0	7.16	1446	32.1
	6.60	10	2.0	11.0	7.16	1446	50.5
	7.62	12	1.8	10.8	7.16	1446	70.3
	8.64	14	1.6	10.7	7.17	1484	52.5
	9.66	16	1.3	10.5	7.18	1470	43.0
	10.68	18	1.3	10.5	7.18	1477	28.2
	12.21	21	1.1	10.5	7.18	1470	19.7
	14.76	26	0.9	10.5	7.19	1484	11.2
	17.31	31	0.9	10.4	7.20	1484	7.8
	19.86	36	0.7	10.5	7.19	1519	6.23
	22.41	41	0.7	10.5	7.19	1526	5.46
	24.96	46	0.7	10.5	7.19	1512	4.55
	27.51	51	0.7	10.5	7.19	1498	4.12
	30.06	56	0.6	10.4	7.19	1505	3.30
	32.61	61	0.7	10.4	7.20	1498	2.68
	35.16	66	0.6	10.4	7.19	1512	2.43
	37.71	71	0.6	10.4	7.20	1498	2.23
CP2 (Q=1000 mL/min)	4.00	4	3.8	10.5	6.89	1428	9.66
	5.00	5	2.8	11.1	6.92	1432	24.4
	6.00	6	2.3	11.4	6.95	1480	26.4
	6.94	7	2.0	11.8	6.99	1458	21.3
	8.82	9	1.8	11.8	7.01	1458	58.3
	10.70	11	1.4	11.6	7.04	1514	47.0
	12.58	13	1.1	11.5	7.06	1507	27.2
	14.46	15	0.9	11.5	7.08	1514	16.8

continued

TABLE A–1. VALUES OF FIELD PARAMETERS DURING PURGING

Well ID/Device	Vol (L)	Time (min)	DO (mg/L)	T (°C)	pH	EC (µS)	Turb. (NTU)
CP2 (Q=1000 mL/min)	16.34	17	0.8	11.5	7.09	1507	12.3
	18.22	19	0.7	11.4	7.10	1493	8.30
	20.10	21	0.6	11.4	7.11	1527	5.8
	21.98	23	0.6	11.3	7.11	1521	4.6
	23.86	25	0.5	11.3	7.12	1514	3.5
	25.46	27	0.5	11.1	7.12	1507	3.1
	26.46	29	0.9	11.9	7.12	1498	3.8
	29.98	33	0.4	11.8	7.11	1478	49.2
	32.06	36	0.3	11.4	7.12	1521	138.3
	32.90	37	2.8	11.1	7.07	1555	96.6
	33.80	38	0.8	12.0	7.06	1528	58.5
	35.60	40	0.6	11.8	7.10	1491	52.6
	39.20	44	0.4	11.4	7.12	1526	50.2
	41.00	46	0.4	11.2	7.12	1527	35.3
	43.2	48	0.3	12.0	7.12	1517	18.0
	45.4	50	0.3	11.8	7.13	1498	12.2
	47.6	52	0.3	11.6	7.13	1527	11.3
	54.6	56	0.5	11.6	7.11	1508	17.1
	57.8	58	0.5	12.0	7.12	1517	10.5
	62.4	61	0.3	11.5	7.13	1514	7.9
	64.8	63	0.3	11.4	7.13	1500	5.9
Bail	41.6	21	4.6	14.9	7.23	1490	>2000
NEV–1							
CP1 (Q=310 mL/min)	1.50	5	0.80	24.50	6.82	23.20	0.29
	3.30	11	0.70	25.60	6.85	23.20	0.13
	3.94	13	0.70	25.90	6.88	22.90	0.13
	4.58	15	0.70	26.10	6.89	22.90	0.11
	5.22	17	0.70	26.10	6.89	23.00	0.10
	5.86	19	0.70	26.20	6.90	23.00	0.10
	6.50	21	0.60	26.20	6.91	23.00	0.09
	7.16	23	0.60	26.20	6.91	23.00	0.10
	7.82	25	0.50	26.30	6.91	23.00	0.08
	8.50	27	0.50	26.40	6.91	22.70	0.08
	9.18	29	0.60	26.40	6.91	22.60	0.07
	9.78	31	0.50	26.40	6.92	22.60	0.07
	10.38	33	0.40	26.60	6.92	22.70	0.07
	10.98	35	0.40	26.60	6.92	22.70	0.06
	11.58	37	0.50	26.50	6.92	22.60	0.07
	12.18	39	0.40	26.50	6.92	22.60	0.06
	12.78	41	0.40	26.50	6.92	22.60	0.06
	13.36	43	0.40	26.50	6.92	22.60	0.05
	13.94	45	0.40	26.40	6.92	22.60	0.06
	14.52	47	0.40	26.40	6.92	22.60	0.06
BP (Q=990 mL/min)	0.74	1	2.90	22.10	6.86	22.70	0.30
	1.48	2	1.70	23.10	6.86	23.10	0.18
	2.22	3	1.10	23.60	6.88	23.00	0.86
	2.96	4	0.70	24.00	6.89	23.10	0.46
	5.36	6	0.40	24.20	6.90	23.10	0.14
	6.46	7	0.40	24.20	6.90	23.10	0.13

continued

TABLE A–1. VALUES OF FIELD PARAMETERS DURING PURGING

Well ID/Device	Vol (L)	Time (min)	DO (mg/L)	T (°C)	pH	EC (µS)	Turb. (NTU)
BP (Q=990 mL/min)	7.56	8	0.30	24.30	6.90	23.10	0.14
	9.54	10	0.30	24.30	6.90	23.10	0.14
	11.40	12	0.30	24.40	6.90	23.00	0.12
	13.26	14	0.30	24.50	6.90	23.10	0.10
	15.12	16	0.20	24.50	6.90	23.10	0.08
	16.98	18	0.20	24.50	6.90	23.00	0.08
	18.96	20	0.20	24.50	6.89	23.00	0.07
	20.94	22	0.20	24.60	6.89	23.00	0.08
	22.84	24	0.20	24.60	6.89	23.10	0.06
	24.82	26	0.20	24.50	6.89	23.00	0.05
	26.80	28	0.20	24.50	6.89	23.00	0.05
	28.74	30	0.20	24.50	6.89	22.90	0.05
	30.68	32	0.20	24.60	6.89	22.90	0.05
	32.62	34	0.20	24.60	6.89	22.90	0.05
CP2 (Q=990 mL/min)	0.90	1	1.70	23.00	6.84	22.70	0.60
	2.70	3	0.70	24.40	6.80	23.10	0.37
	4.50	5	0.40	25.30	6.82	22.90	0.24
	6.44	7	0.30	25.50	6.86	23.10	0.23
	8.38	9	0.30	25.60	6.89	23.10	0.16
	10.32	11	0.20	25.70	6.89	23.10	0.13
	12.26	13	0.20	25.80	6.89	22.70	0.13
	14.20	15	0.20	25.80	6.89	22.60	0.13
	16.14	17	0.20	25.80	6.89	22.60	0.13
	18.10	19	0.20	25.80	6.89	22.60	0.10
	20.06	21	0.20	25.80	6.89	22.60	0.09
	22.02	23	0.20	25.80	6.89	22.70	0.07
	24.00	25	0.20	25.90	6.89	22.70	0.08
	25.98	27	0.20	25.90	6.89	22.70	0.08
	27.96	29	0.20	25.90	6.89	22.60	0.07
	29.94	31	0.20	25.90	6.89	22.60	0.06
Bail	4.60	10	3.00	22.40	7.05	22.90	45.00
	23.00	20	2.30	23.40	7.02	22.70	96.50
	35.00	28	2.30	24.10	6.99	22.60	82.80
	46.00	34	2.90	24.00	7.04	22.60	118.30
	58.00	42	2.70	24.10	7.07	22.60	110.20
	69.00	60	2.30	23.80	7.18	22.50	113.50
	80.00	69	2.50	24.10	7.03	22.50	104.20
	92.00	74	2.50	24.00	7.08	22.50	104.70
	103.00	78	2.40	23.90	7.10	22.50	89.20
	115.00	89	2.30	24.20	7.11	22.60	66.00
	126.00	107	2.50	24.10	7.13	22.60	80.70
	138.00	117	2.80	24.30	7.07	22.60	67.20
NEV–2							
CP1 (Q=310 mL/min)	0.60	3	2.10	24.20	7.04	20.80	17.60
	0.98	5	1.40	24.30	7.01	20.90	11.50
	1.36	7	1.00	24.50	6.97	21.00	9.30
	1.88	9	0.80	25.50	6.93	20.90	9.20
	2.42	11	0.60	26.70	6.93	21.20	5.05
	3.66	13	0.50	26.90	6.93	20.90	3.88

continued

TABLE A–1. VALUES OF FIELD PARAMETERS DURING PURGING

Well ID/Device	Vol (L)	Time (min)	DO (mg/L)	T (°C)	pH	EC (µS)	Turb. (NTU)
CP1 (Q=310 mL/min)	4.28	15	0.40	27.10	6.93	21.00	3.56
	4.90	17	0.40	27.10	6.93	21.00	3.33
	5.52	19	0.40	27.20	6.93	21.00	3.12
	6.14	21	0.40	27.20	6.93	21.00	2.96
	6.76	23	0.30	27.30	6.93	21.10	2.77
	7.38	25	0.30	27.30	6.93	21.10	2.94
	8.00	27	0.30	27.30	6.93	21.10	2.70
	8.62	29	0.30	27.40	6.92	21.10	2.69
	9.24	31	0.30	27.50	6.92	21.20	2.62
	9.86	33	0.30	27.50	6.92	21.20	2.37
	10.50	35	0.30	27.50	6.92	21.20	2.28
	11.14	37	0.30	27.50	6.92	21.20	2.16
	11.77	39	0.30	27.40	6.92	21.20	1.90
	12.40	41	0.30	27.40	6.92	21.20	1.87
	13.03	43	0.20	27.50	6.92	21.20	1.68
	13.65	45	0.20	27.50	6.92	21.20	1.50
	14.27	47	0.20	27.50	6.92	21.20	1.63
BP (Q=970 mL/min)	0.95	1	2.60	22.60	6.94	20.10	6.90
	1.90	2	2.00	23.30	6.86	21.10	5.33
	2.85	3	1.50	23.70	6.87	21.10	4.62
	3.80	4	1.00	23.90	6.88	21.20	3.68
	4.75	5	0.90	24.00	6.88	21.20	2.30
	5.70	6	0.70	24.10	6.88	21.20	2.08
	6.67	7	0.60	24.20	6.88	21.20	1.47
	7.64	8	0.50	24.20	6.88	21.20	1.29
	8.62	9	0.50	23.50	6.89	21.30	1.00
	9.59	10	0.40	24.00	6.89	21.10	0.97
	10.56	11	0.40	24.20	6.89	21.20	0.87
	11.53	12	0.30	24.20	6.89	21.10	0.80
	12.50	13	0.30	24.20	6.89	21.10	0.75
	13.47	14	0.30	24.30	6.89	21.10	0.69
	14.44	15	0.30	24.30	6.90	21.20	0.70
	15.41	16	0.20	24.20	6.89	21.10	0.64
	16.38	17	0.20	24.20	6.90	21.10	0.65
	18.32	19	0.20	24.20	6.90	21.20	0.63
	20.26	21	0.20	24.30	6.90	21.20	0.51
	22.20	23	0.20	24.20	6.90	21.00	0.50
	24.14	25	0.20	24.20	6.90	21.00	0.46
	26.12	27	0.20	24.30	6.90	21.10	0.44
	28.06	29	0.20	24.30	6.90	21.00	0.55
	30.00	31	0.20	24.30	6.90	21.10	0.43
CP2 (Q=990 mL/min)	3.00	2	1.00	24.00	6.77	21.30	11.55
	4.20	3	0.50	25.10	6.80	21.50	4.84
	5.40	4	0.40	25.40	6.86	21.60	2.72
	6.60	5	0.40	25.70	6.87	21.70	1.63
	7.80	6	0.30	25.80	6.87	21.30	1.08
	8.90	7	0.30	25.90	6.88	21.40	0.61
	10.00	8	0.30	26.00	6.88	21.40	0.56

continued

TABLE A–1. VALUES OF FIELD PARAMETERS DURING PURGING

Well ID/Device	Vol (L)	Time (min)	DO (mg/L)	T (°C)	pH	EC (μS)	Turb. (NTU)
CP2 (Q=990 mL/min)	10.99	9	0.30	26.10	6.88	21.50	0.46
	12.97	11	0.20	26.20	6.89	21.60	0.50
	14.93	13	0.20	26.10	6.89	21.50	0.41
	16.89	15	0.20	26.20	6.89	21.60	0.36
	18.85	17	0.20	26.10	6.89	21.60	0.36
	20.81	19	0.20	26.20	6.89	21.60	0.34
	22.79	21	0.20	26.20	6.89	21.70	0.33
	24.77	23	0.20	26.20	6.89	21.70	0.30
	26.75	25	0.10	26.20	6.89	21.70	0.30
	28.73	27	0.10	26.20	6.89	21.70	0.26
	30.71	29	0.10	26.20	6.88	21.70	0.28
Bail	2.76	5	3.80	21.60	7.15	21.40	46.00
	6.44	9	2.20	22.80	7.14	21.10	138.60
	12.88	15	2.50	22.70	7.10	21.50	185.00
	19.32	19	3.40	23.30	7.14	21.30	162.00
	25.76	32	3.50	22.90	7.13	21.20	304.00
	32.20	40	3.30	22.90	7.17	21.30	380.00
	38.64	55	3.30	22.30	7.13	21.60	448.00
WASH–1							
CP1 (Q=300 mL/min)	0.14	1	2.8	7.0	8.77	808	128.8
	0.28	2	1.9	7.1	8.35	810	122.9
	0.42	3	1.3	7.0	8.08	810	109.4
	0.70	5	1.0	6.8	7.90	823	89.6
	1.30	7	1.0	5.9	7.74	805	75.8
	1.90	9	0.6	7.8	7.56	781	52.9
	2.38	11	0.5	9.4	7.44	775	38.8
	3.26	13	0.4	12.6	7.38	767	36.5
	3.88	15	0.4	13.7	7.39	811	24.9
	4.50	17	0.4	13.2	7.42	816	21.8
	5.10	19	0.3	12.8	7.43	809	18.3
	5.70	21	0.3	13.2	7.43	814	13.26
	6.38	23	0.3	13.5	7.44	816	11.85
	7.06	25	0.3	14.0	7.45	809	10.79
	7.66	27	0.3	14.2	7.46	809	10.27
	8.26	29	0.3	13.7	7.48	824	10.72
	8.86	31	0.3	13.7	7.48	804	11.09
	9.46	33	0.3	13.9	7.49	809	12.24
	10.06	35	0.3	13.8	7.51	814	12.22
	10.66	37	0.3	13.8	7.52	818	11.50
	11.26	39	0.3	13.6	7.54	838	9.48
	11.86	41	0.3	13.4	7.54	829	8.36
	12.46	43	0.2	13.2	7.55	824	7.78
	13.06	45	0.2	13.1	7.55	819	6.49
	13.46	47	0.2	13.0	7.55	824	5.75
	13.86	49	0.3	12.8	7.56	822	4.67
	15.36	54	0.3	15.4	7.56	824	16.4
	15.96	56	0.2	15.8	7.56	822	5.80
	16.56	58	0.2	15.1	7.57	829	5.52

continued

TABLE A–1. VALUES OF FIELD PARAMETERS DURING PURGING

Well ID/Device	Vol (L)	Time (min)	DO (mg/L)	T (°C)	pH	EC (µS)	Turb. (NTU)
CP1 (Q=300 mL/min)	16.86	59	0.4	13.9	7.58	828	8.02
	17.46	61	0.4	13.2	7.58	827	15.35
	18.34	63	0.5	13.4	7.57	807	16.73
	18.94	65	0.3	15.4	7.56	824	10.54
	19.54	67	0.3	15.2	7.56	826	9.79
	20.14	69	0.4	14.0	7.57	821	10.32
	20.74	71	0.4	13.2	7.57	819	10.62
	21.20	73	0.4	13.7	7.57	827	10.50
	21.36	75	0.4	13.7	7.57	835	9.41
	21.96	77	0.4	13.4	7.57	827	9.21
	22.78	79	0.4	12.9	7.57	811	9.25
	23.58	81	0.4	15.4	7.56	824	6.28
	24.14	83	0.3	15.9	7.57	827	5.70
	24.46	85	0.4	15.3	7.57	829	7.24
	24.82	87	0.5	15.4	7.57	817	11.23
BP (Q=100 0 mL/min)	0.60	2	7.1	7.5	7.28	554	
	1.40	4	4.5	8.3	7.28	710	178.9
	2.00	5	4.2	8.7	7.32	747	169.2
	2.80	6	4.1	9.6	7.41	781	109.8
	3.76	7	3.7	9.8	7.42	773	87.2
	5.69	9	3.1	10.0	7.35	771	86.3
	6.64	10	2.8	10.1	7.35	777	83.6
	7.62	11	2.8	10.2	7.34	775	89.7
	8.60	12	3.1	10.2	7.35	787	77.2
	9.58	13	2.9	10.2	7.35	787	70.3
	10.56	14	3.1	10.2	7.38	795	63.9
	11.54	15	4.1	10.3	7.42	801	79.3
	12.52	16	4.3	10.3	7.45	803	74.0
	13.50	17	4.8	10.3	7.49	810	66.3
	14.48	18	4.8	10.3	7.52	812	68.1
	15.46	19	4.2	10.3	7.55	819	75.4
	16.44	20	4.2	10.4	7.57	827	78.3
	17.42	21	3.9	10.4	7.58	831	83.3
	18.41	22	3.8	10.3	7.57	827	93.1
	19.40	23	3.4	10.3	7.58	838	94.3
	21.38	25	3.4	10.4	7.57	850	101.3
	23.38	27	3.2	10.4	7.56	861	92.2
	25.38	29	3.4	10.4	7.58	883	94.1
	27.38	31	3.7	10.4	7.56	886	123.3
	29.38	33	4.2	10.4	7.55	892	164.2
	33.38	37	5.3	10.4	7.54	894	220
	38.38	42	5.7	10.4	7.56	866	
	39.38	43	5.2	10.4	7.57	864	330
	41.38	45	5.7	10.4	7.59	855	
	43.38	47	5.6	10.4	7.59	855	
	49.38	53	5.3	10.4	7.61	852	370
	55.60	70	5.1	9.8	7.52	840	
	56.60	71	5.0	10.2	7.54	844	160

continued

TABLE A–1. VALUES OF FIELD PARAMETERS DURING PURGING

Well ID/Device	Vol (L)	Time (min)	DO (mg/L)	T (°C)	pH	EC (μS)	Turb. (NTU)
CP2 (Q=950 mL/min)	1.00	1	3.0	7.6	8.09	784	101.9
	2.00	2	2.8	8.2	7.80	787	85.9
	3.00	3	1.9	9.6	7.62	789	67.3
	4.00	4	1.6	10.9	7.55	776	41.8
	5.00	5	1.5	11.2	7.55	785	33.2
	5.96	6	1.5	11.5	7.57	793	28.6
	6.94	7	1.4	11.8	7.60	784	28.1
	7.92	8	1.5	12.3	7.64	797	42.5
	8.92	9	1.9	12.3	7.66	801	77.9
	9.92	10	2.3	12.6	7.71	813	67.5
	10.08	11	2.2	12.8	7.76	803	77.5
	11.10	12	1.5	12.7	7.83	824	133.5
	12.12	13	1.1	12.7	7.85	829	148.0
	13.14	14	0.6	12.8	7.85	816	141.2
	14.16	15	0.5	12.8	7.85	824	143.6
	15.18	16	0.4	12.8	7.85	822	138.6
	16.20	17	0.3	12.9	7.83	844	116.6
	17.22	18	0.3	12.9	7.82	851	115.9
	18.24	19	0.3	12.8	7.83	864	141.8
	20.28	21	0.4	12.9	7.79	883	
	22.32	23	0.4	13.1	7.77	918	
	24.40	27	0.9	11.5	7.86	832	
	26.88	29	2.3	13.2	7.86	832	
	28.88	31	3.0	13.4	7.88	838	440
	32.88	35	2.7	13.7	7.82	880	
	34.88	37	1.9	13.7	7.78	922	400
	37.76	39	1.1	13.6	7.76	922	
	40.64	42	0.7	13.4	7.77	918	
	43.34	45	0.6	13.4	7.77	915	450
	45.14	47	0.7	13.3	7.76	911	
	46.94	49	0.8	13.4	7.75	911	800
	50.50	53	1.1	13.5	7.74	910	
Bail	1.38	2	4.2	12.1	7.10	757	39.8
	3.68	8	4.9	10.8	7.47	772	277.0
	8.28	18	5.2	10.7	7.68	820	390.0
	16.56	37	5.3	10.6	7.76	834	700.0
	24.84	52	5.2	10.5	7.76	872	769.0
	33.12	61	6.0	10.6	7.71	886	1156.0
WASH–2							
CP1 (Q=280 mL/min)	1.02	3	10.3	2.7	9.77	448	22.7
	1.36	4	4.5	3.6	9.11	363	21.3
	1.70	5	3.1	3.7	8.69	296	20.5
	2.04	6	2.2	3.7	8.14	244	17.75
	2.72	8	1.5	3.6	7.30	203	16.89
	3.32	10	1.0	3.1	6.72	147	12.69
	3.92	12	0.8	4.5	6.49	129	11.48
	4.52	14	0.6	7.1	6.32	123	9.54

continued

TABLE A-1. VALUES OF FIELD PARAMETERS DURING PURGING

Well ID/Device	Vol (L)	Time (min)	DO (mg/L)	T (°C)	pH	EC (μS)	Turb. (NTU)
CP1 (Q=280 mL/min)	5.12	16	0.6	7.4	6.24	121	9.34
	5.72	18	0.5	7.3	6.20	126	8.88
	6.32	20	0.4	7.3	6.19	124	8.83
	6.92	22	0.4	7.6	6.18	125	8.49
	7.52	24	0.3	7.8	6.18	123	8.29
	8.12	26	0.3	7.5	6.17	125	8.05
	8.60	28	0.3	7.4	6.18	124	7.73
	8.84	30	0.3	6.7	6.18	125	7.92
	9.30	32	0.2	6.7	6.18	116	8.50
	9.76	34	0.3	6.9	6.18	111	9.18
	10.56	38	0.3	7.0	6.18	111	8.57
	10.80	40	0.3	6.9	6.18	112	7.92
	11.20	44	0.2	5.5	6.19	114	8.02
	11.84	50	0.2	6.2	6.20	112	58.2
	12.48	52	0.2	7.4	6.20	111	51.7
	13.12	54	0.2	8.0	6.20	109	40.2
	13.90	56	0.2	8.1	6.21	110	55.8
	14.42	58	0.2	10.0	6.21	109	39.2
	14.94	60	0.2	10.0	6.21	109	40.2
	15.46	62	0.2	8.5	6.21	113	22.2
	15.98	64	0.2	8.3	6.22	111	23.2
	16.58	66	0.2	8.4	6.22	111	22.5
	17.18	68	0.2	8.5	6.22	112	21.4
	17.78	70	0.2	8.2	6.22	112	20.4
	18.38	72	0.2	7.3	6.22	113	17.4
	18.98	74	0.2	6.9	6.23	111	17.6
	19.58	76	0.2	6.5	6.24	113	16.2
	20.78	80	0.2	9.3	6.21	111	16.5
	22.38	84	0.2	9.1	6.22	111	13.0
	23.54	88	0.2	8.3	6.22	111	11.5
	24.12	90	0.2	7.8	6.23	110	10.8
	24.70	92	0.2	7.5	6.23	113	10.7
	25.28	94	0.2	7.1	6.23	112	10.6
	26.16	96	0.2	7.5	6.23	112	10.8
	26.72	98	0.2	9.3	6.23	110	13.7
	27.28	100	0.2	9.4	6.22	111	10.9
	27.84	102	0.2	8.6	6.23	112	10.3
	28.40	104	0.2	7.1	6.23	112	10.3
	28.96	106	0.2	7.5	6.24	112	9.8
	29.52	108	0.2	9.5	6.23	111	11.0
	30.08	110	0.2	9.2	6.22	111	10.3
	30.64	112	0.2	9.2	6.22	111	9.3
	31.20	114	0.2	9.2	6.22	111	9.0
BP (Q=1000 mL/min)	1.88	2	4.9	6.7	6.65	104	42.3
	2.82	3	1.3	7.8	6.40	109	31.2
	3.82	4	0.8	8.2	6.30	110	29.8
	4.82	5	0.5	8.4	6.27	110	28.2
	5.82	6	0.5	8.5	6.25	110	25.2

continued

TABLE A–1. VALUES OF FIELD PARAMETERS DURING PURGING

Well ID/Device	Vol (L)	Time (min)	DO (mg/L)	T (°C)	pH	EC (µS)	Turb. (NTU)
BP (Q=1000 mL/min)	6.82	7	0.4	8.6	6.24	110	23.2
	7.82	8	0.4	8.7	6.24	110	20.5
	8.82	9	0.3	8.7	6.24	111	19.7
	10.82	11	0.3	8.6	6.24	110	16.7
	12.82	13	0.2	8.7	6.24	111	15.3
	14.82	15	0.2	8.8	6.24	108	13.7
	16.82	17	0.2	8.7	6.22	110	12.3
	18.82	19	0.2	8.7	6.18	110	12.2
	20.82	21	0.2	8.8	6.18	107	11.1
	22.82	23	0.2	8.9	6.21	108	10.8
	24.82	25	0.2	8.9	6.23	108	10.3
	26.82	27	0.1	8.8	6.22	107	10.8
	28.82	29	0.1	8.7	6.21	110	9.7
	29.82	30	0.1	8.7	6.20	110	9.3
	31.82	32	0.1	8.6	6.20	110	9.3
	33.82	34	0.1	8.7	6.20	110	9.2
	37.82	38	0.1	8.6	6.19	110	8.8
	39.82	40	0.1	8.6	6.19	110	8.9
	41.82	42	0.1	8.6	6.13	110	8.5
	43.82	44	0.1	8.6	6.14	110	8.4
CP2 (Q=1040 mL/min)	1.00	1	4.8	5.5	8.18	94.4	67.3
	2.00	2	2.4	8.1	6.91	113	28.2
	3.00	3	1.2	8.8	6.57	113	21.3
	4.00	4	0.8	9.4	6.50	113	17.3
	5.20	5	0.5	9.9	6.45	110	14.5
	6.40	6	0.3	10.1	6.42	111	11.48
	7.58	7	0.3	10.0	6.42	110	10.49
	8.76	8	0.3	10.0	6.42	110	10.22
	9.80	9	0.3	10.3	6.42	110	9.53
	10.84	10	0.2	10.3	6.42	111	9.21
	11.88	11	0.2	10.2	6.42	110	8.96
	12.92	12	0.2	10.3	6.43	110	8.23
	13.96	13	0.2	10.3	6.43	111	8.63
	15.02	14	0.2	10.4	6.43	110	7.73
	16.08	15	0.2	10.5	6.42	111	8.32
	17.16	16	0.2	10.5	6.43	111	7.65
	18.18	17	0.2	10.4	6.43	110	7.82
	19.20	18	0.2	10.4	6.42	111	7.82
	20.22	19	0.2	10.3	6.43	111	7.44
	21.24	20	0.1	10.3	6.43	111	7.35
	22.28	21	0.1	10.3	6.43	110	7.16
	23.32	22	0.1	10.3	6.43	111	7.20
	24.36	23	0.1	10.2	6.43	111	7.03
	25.40	24	0.1	10.4	6.43	111	7.06
	26.44	25	0.1	10.3	6.43	111	6.86
	27.48	26	0.1	10.3	6.43	111	6.81
	28.52	27	0.1	10.2	6.43	110	6.72
	29.56	28	0.1	10.0	6.43	110	6.64

continued

TABLE A–1. VALUES OF FIELD PARAMETERS DURING PURGING

Well ID/Device	Vol (L)	Time (min)	DO (mg/L)	T (°C)	pH	EC (µS)	Turb. (NTU)
CP2 (Q=1040 mL/min)	30.60	29	0.1	9.9	6.43	110	6.65
	32.68	31	0.1	10.1	6.43	110	6.60
	33.72	32	0.1	10.3	6.43	111	6.50
	34.76	33	0.1	10.3	6.43	111	6.49
	36.76	35	0.1	9.9	6.43	110	6.39
	37.80	36	0.1	9.8	6.43	109	6.28
Bail	6.44	6	3.3	9.2	7.15	120	414.0
	12.88	12	2.6	9.5	6.63	112	695.0
	19.32	17	2.8	9.5	6.51	113	735.0
	25.76	24	3.1	9.4	6.47	112	720.0
	32.20	32	3.5	9.4	6.45	113	735.0
WASH–3							
CP1 (Q=300 mL/min)	1.80	3	4.2	8.1	6.62	1017	33.5
	2.60	5	1.8	9.2	6.55	1105	24.3
	3.80	7	0.8	10.0	6.55	1079	7.3
	4.28	9	0.8	10.0	6.55	1054	8.08
	4.88	11	0.7	9.8	6.54	1047	9.03
	5.64	13	0.4	9.3	6.53	998	7.40
	6.36	15	0.4	9.8	6.53	978	10.28
	6.96	17	0.3	9.9	6.53	969	10.22
	7.26	18	0.3	9.8	6.52	941	8.50
	8.16	21	0.3	9.7	6.52	952	9.20
	8.76	23	0.3	9.8	6.51	924	9.06
	9.36	25	0.3	10.0	6.50	921	9.58
	9.96	27	0.3	10.0	6.50	910	8.93
	10.56	29	0.3	10.2	6.49	901	7.62
	11.16	31	0.3	10.3	6.48	894	7.32
	11.76	33	0.3	10.3	6.48	886	7.08
	12.36	35	0.3	10.0	6.47	875	6.97
	12.96	37	0.2	10.0	6.47	864	6.51
	13.56	39	0.2	10.3	6.47	864	6.20
	14.16	41	0.2	10.4	6.46	861	5.96
	14.76	43	0.2	10.2	6.45	840	5.55
	15.36	45	0.2	10.2	6.45	836	5.28
	15.96	47	0.2	10.3	6.45	834	5.06
	16.60	49	0.2	10.4	6.44	831	4.92
	17.20	51	0.2	10.1	6.44	820	4.57
	17.80	53	0.2	10.1	6.44	819	4.38
	18.40	55	0.2	10.4	6.44	808	4.25
	19.00	57	0.2	10.2	6.43	796	4.02
	19.60	59	0.2	10.2	6.43	792	3.88
	20.20	63	0.2	9.9	6.42	773	3.82
	20.80	65	0.2	9.9	6.42	768	4.43
	21.40	67	0.2	9.7	6.42	792	3.89
	22.00	69	0.2	9.4	6.42	776	3.85
	22.60	71	0.2	9.1	6.42	768	3.62
	23.20	73	0.2	9.2	6.42	776	3.52
	23.96	75	0.2	9.5	6.42	784	3.68

continued

TABLE A–1. VALUES OF FIELD PARAMETERS DURING PURGING

Well ID/Device	Vol (L)	Time (min)	DO (mg/L)	T (°C)	pH	EC (µS)	Turb. (NTU)
CP1 (Q=300 mL/min)	24.68	77	0.2	9.7	6.41	775	3.45
	25.28	79	0.2	9.6	6.41	765	3.28
	25.88	81	0.2	9.5	6.41	769	3.32
	26.48	83	0.2	9.4	6.41	759	3.28
	27.12	85	0.2	9.3	6.41	765	2.98
	27.72	87	0.2	9.1	6.41	759	2.89
	28.32	89	0.2	9.2	6.41	759	3.08
BP (Q=980 mL/min)	2.20	2	7.7	9.4	6.78	664	10.66
	3.04	3	3.4	10.4	6.62	969	10.28
	3.94	4	2.3	10.4	6.53	938	8.28
	5.80	6	1.4	10.3	6.42	915	4.96
	6.76	7	1.2	10.2	6.37	869	4.35
	7.74	8	1.0	10.2	6.33	847	4.18
	8.72	9	1.0	10.2	6.32	815	4.16
	9.70	10	0.8	10.1	6.30	808	4.14
	10.68	11	0.8	10.1	6.27	780	3.96
	11.64	12	0.7	10.0	6.23	759	3.88
	13.64	14	0.6	10.0	6.18	729	3.72
	15.64	16	0.6	10.0	6.18	719	3.53
	17.64	18	0.5	9.8	6.15	694	3.48
	19.64	20	0.5	9.9	6.13	686	3.38
	21.64	22	0.5	9.8	6.11	682	3.40
	23.64	24	0.4	9.8	6.09	673	3.41
	25.64	26	0.4	9.8	6.07	665	3.26
	27.60	28	0.4	9.8	6.11	661	3.22
	31.52	32	0.4	9.8	6.12	654	4.42
	33.48	34	0.4	9.8	6.11	649	3.28
	35.44	36	0.4	9.8	6.07	666	3.46
	37.36	38	0.4	9.8	6.07	650	3.18
	39.28	40	0.4	9.8	6.10	642	3.53
	41.20	42	0.3	9.7	6.11	640	2.92
	43.12	44	0.3	9.7	6.10	654	3.31
CP2 (Q=1100 mL/min)	0.860	1	5.8	7.0	7.21	864	42.2
	1.72	2	2.4	8.7	6.52	873	16.5
	2.58	3	1.1	9.4	6.51	978	6.92
	3.44	4	0.6	9.9	6.53	955	5.73
	4.44	5	0.4	10.5	6.54	932	8.3
	5.44	6	0.3	11.0	6.53	886	5.8
	6.44	7	0.3	11.2	6.53	874	5.8
	7.44	8	0.3	11.3	6.53	855	5.7
	8.44	9	0.2	11.2	6.50	839	5.1
	9.60	10	0.3	11.0	6.50	814	5.2
	10.76	11	0.3	11.2	6.49	791	4.9
	11.92	12	0.3	11.1	6.48	770	5.5
	13.12	13	0.3	10.9	6.48	659	5.8
	15.52	15	0.3	10.9	6.48	751	4.9
	16.72	16	0.3	11.0	6.47	744	5.7
	19.12	18	0.3	10.9	6.47	743	5.7
	21.28	20	0.3	11.0	6.46	739	5.6

continued

TABLE A–1. VALUES OF FIELD PARAMETERS DURING PURGING

Well ID/Device	Vol (L)	Time (min)	DO (mg/L)	T (°C)	pH	EC (µS)	Turb. (NTU)
CP2 (Q=1100 mL/min)	23.44	22	0.3	10.9	6.46	729	4.7
	25.76	24	0.3	10.6	6.46	729	5.7
	28.08	26	0.3	10.6	6.45	724	4.9
	30.40	28	0.3	10.7	6.45	724	4.6
	32.72	30	0.3	10.8	6.45	703	4.9
	34.88	32	0.3	10.9	6.44	702	4.6
	37.04	34	0.3	10.8	6.44	714	4.2
Bail	3.22	4	2.7	10.3	6.81	861	48.3
	6.90	8	2.6	10.1	6.99	824	32.2
	13.80	18	2.7	9.8	7.08	722	21.0
	20.70	23	3.4	9.6	6.99	692	18.3
	27.60	31	3.3	9.5	7.04	687	10.3

TABLE A-2. VOLUMES AND TIMES AT WHICH INDICATOR PARAMETERS REACHED EQUILIBRIUM VALUES

Well ID	Device	Volume (L)	Screen Volumes	Time (min)
WISC–2	CP1	19.3[a]	2.1	50
	BP	15.2	1.6	30
	CP2	17.9[a]	1.9	19
	Bailer	65.3[b]	7.0	33
WISC–3	CP1	16.9	1.8	43
	CP2	27.1	2.9	29
	Bailer	56.8[b]	6.1	28
WISC–4	CP1	29.1[c]	4.7	89
	BP	32.6	5.3	61
	CP2	64.8[c]	10.5	63
	Bailer	41.6[b]	6.7	21
NEV–1	CP1	11.6	0.2	37
	BP	13.3	0.3	14
	CP2	12.3	0.2	13
	Bailer	138[c]	2.8	117
NEV–2	CP1	9.2	7.7	31
	BP	11.5	9.6	12
	CP2	13.0	10.8	11
	Bailer	38.6[d]	32.2	55
WASH–1	CP1	24.8[c]	4.0	87
	BP	56.6[c]	9.1	61
	CP2	50.5[c]	8.1	53
	Bailer	33.1[d]	5.3	61
WASH–2	CP1	9.30[d]	1.5	32
	BP	29.8	4.8	30
	CP2	22.3[a]	3.6	21
	Bailer	32.2[d]	5.2	32
WASH–3	CP1	19.0[a]	3.1	57
	BP	23.6	3.8	24
	CP2	23.4[a]	3.8	22
	Bailer	27.6[d]	4.5	31

[a] Temperature did not reach equilibrium.
[b] Pre–determined purge volume.
[c] Dissolved oxygen, temperature, and turbididity did not reach equilibrium. Purged volume shown is volume at which samples were collected.
[d] Dissolved oxygen and turbidity did not reach equilibrium, purged volume shown is volume at which samples were collected.

APPENDIX B
Summary of Particle Size Analysis

TABLE B–1. SUMMARY OF PARTICLE SIZE ANALYSIS

ID	Concentration (mg/L)						Weight Fraction		
	>5.0 µm	5.0–0.4 µm	0.4–0.1 µm	0.1–0.03 µm	Total	0.4–0.03 µm	>5.0µm	0.4–0.03 µm	>0.4 µm
WISC–1									
BP	16.2	5.9	1.2	0.0	23.3	1.2	0.70	0.05	0.95
WISC–2									
CP1	0.5	0.1	0.1	0	0.7	0.1	0.71	0.14	0.86
BP	0	0.5	0.2	0	0.7	0.2	0.00	0.29	0.71
CP2	0.6	0.2	0.1	0.2	1.1	0.3	0.55	0.27	0.73
Bail	113.6	7.6	0.6	0.5	122.3	1.1	0.93	0.01	0.99
WISC–3									
CP1	0.4	0.8	0	1.6	2.8	1.6	0.14	0.57	0.43
CP2	0.1	0.5	0	0.4	1	0.4	0.10	0.40	0.60
Bail	169	6.4	1.8	2.6	179.8	4.4	0.94	0.02	0.98
WISC–4									
CP1	131	4.4	0.5	0.2	136.1	0.7	0.96	0.01	0.99
BP	2.2	0.8	0	0.1	3.1	0.1	0.71	0.03	0.97
CP2	0	0.4	0	0	0.4	0	0.00	0.00	1.00
Bail	6956	8	1.2	0	6965.2	1.2	1.00	0.00	1.00
NEV–1									
CP1	2.2	2.2	0.6	1	6	1.6	0.37	0.27	0.73
BP	0	0.6	1.5	2.2	4.3	3.7	0.00	0.86	0.14
CP2	0.9	0.6	0.8	11	13.3	11.8	0.07	0.89	0.11
Bail	72.4	2.1	2	10.4	86.9	12.4	0.83	0.14	0.86
NEV–2									
CP1	1.8	1	0.8	0.4	4	1.2	0.45	0.30	0.70
BP	1.9	0	0	0.8	2.7	0.8	0.70	0.30	0.70
CP2	0.2	0.9	0	1.6	2.7	1.6	0.07	0.59	0.41
Bail	630	3.1	1.1	0.5	634.7	1.6	0.99	0.00	1.00
WASH–1									
CP1	29.5	0.6	0.1	0	30.2	0.1	0.98	0.00	1.00
BP	105.5	94.1	0.1	0.4	200.1	0.5	0.53	0.00	1.00
CP2	1300	2.9	0	0.4	1303.3	0.4	1.00	0.00	1.00
Bail	841.9	2.5	0.4	0.4	845.2	0.8	1.00	0.00	1.00
WASH-2									
CP1	2	6.4	0.5	0	8.9	0.5	0.22	0.94	0.94
BP	2.6	6.6	1.5	24.3	35	25.8	0.07	0.26	0.26
CP2	2.2	1.1	3.2	4.9	11.4	8.1	0.19	0.29	0.29
Bail	807.3	8.9	0.5	0.9	817.6	1.4	0.99	1.00	1.00
WASH-3									
CP1	17.9	20.1	1.1	0	39.1	1.1	0.46	0.97	0.97
BP	36.9	2.4	0.6	0.5	40.4	1.1	0.91	0.97	0.97
CP2	38.1	3	0	0	41.1	0	0.93	1.00	1.00
Bail	30.3	8.3	1.1	0.6	40.3	1.7	0.75	0.96	0.96

APPENDIX C
Summary of Analytical Results

TABLE C–1. TRACE METALS ANALYTICAL RESULTS (CONCENTRATIONS EXPRESSED AS MG/L)

Device/Filtration Type	Cd	Cr	Fe	Pb	Mn	As	Ba
WISC–1							
BP, unfilt.	<0.005	<0.02	2.8	<0.05	5.0	<0.002	0.137
BP, unfilt.	<0.005	<0.02	0.93	<0.05	4.9	<0.002	0.134
BP, 0.45 um	<0.005	<0.02	0.20	<0.05	4.9	<0.002	0.137
BP, 0.45 um	<0.005	<0.02	0.27	<0.05	4.9	<0.002	0.138
Bail, 0.45 um	<0.005	<0.02	6.1	<0.05	4.88	0.002	0.136
Bail, 0.45 um	<0.005	<0.02	6.2	<0.05	4.88	<0.002	0.137
WISC–2							
CP1, unfilt.	<0.005	<0.02	0.05	<0.05	0.01	<0.002	0.010
CP1, unfilt.	<0.005	<0.02	0.05	<0.05	0.02	<0.002	0.010
CP1, 0.45 um	<0.005	<0.02	<0.01	<0.05	<0.01	<0.002	0.010
CP1, 0.45 um	<0.005	<0.02	0.01	<0.05	<0.01	<0.002	0.010
CP1, 5.0 um	<0.005	<0.02	0.04	<0.05	<0.01	<0.002	0.010
CP1, 5.0 um	<0.005	<0.02	0.03	<0.05	<0.01	<0.002	0.010
BP, unfilt.	<0.005	<0.02	0.07	<0.05	<0.01	<0.002	0.010
BP, unfilt.	<0.005	<0.02	0.07	<0.05	<0.01	<0.002	0.010
BP, 0.45 um	<0.005	<0.02	0.03	<0.05	<0.01	<0.002	0.010
BP, 0.45 um	<0.005	<0.02	0.03	<0.05	<0.01	<0.002	0.010
BP, 5.0 um	<0.005	<0.02	0.02	<0.05	<0.01	<0.002	0.010
BP, 5.0 um	<0.005	<0.02	<0.01	<0.05	<0.01	<0.002	0.010
CP2, unfilt.	<0.005	<0.02	0.11	<0.05	<0.01	<0.002	0.010
CP2, unfilt.	<0.005	<0.02	0.11	<0.05	<0.01	<0.002	0.010
CP2, 0.45 um	<0.005	<0.02	<0.01	<0.05	<0.01	<0.002	0.010
CP2, 0.45 um	<0.005	<0.02	<0.01	<0.05	<0.01	<0.002	0.010
CP2, 5.0 um	<0.005	<0.02	0.02	<0.05	<0.01	<0.002	0.010
CP2, 5.0 um	<0.005	<0.02	0.03	<0.05	<0.01	<0.002	0.010
Bail, unfilt.	<0.005	<0.02	3.5	<0.05	0.11	<0.002	0.044
Bail, unfilt.	<0.005	<0.02	3.3	<0.05	0.10	<0.002	0.036
Bail, 0.45 um	<0.005	<0.02	0.01	<0.05	0.02	<0.002	0.013
Bail, 0.45 um	<0.005	<0.02	<0.01	<0.05	0.01	<0.002	0.012
WISC–3							
CP1, unfilt.	<0.005	<0.02	0.04	<0.05	<0.01	<0.002	0.010
CP1, unfilt.	<0.005	<0.02	0.05	<0.05	0.01	<0.002	0.010
CP1, 0.45 um	<0.005	<0.02	0.02	<0.05	<0.01	<0.002	0.011
CP1, 0.45 um	<0.005	<0.02	0.01	<0.05	<0.01	<0.002	0.012
CP2, unfilt.	<0.005	<0.02	0.05	<0.05	<0.01	<0.002	0.010
CP2, unfilt.	<0.005	<0.02	0.04	<0.05	<0.01	<0.002	0.009
CP2, 0.45 um	<0.005	<0.02	0.01	<0.05	<0.01	<0.002	0.010
CP2, 0.45 um	<0.005	<0.02	0.03	<0.05	<0.01	<0.002	0.010
Bail, unfilt.	<0.005	<0.02	6.47	<0.05	0.14	<0.002	0.054

continued

TABLE C–1. TRACE METALS ANALYTICAL RESULTS (CONCENTRATIONS EXPRESSED AS MG/L)

Device/Filtration Type	Cd	Cr	Fe	Pb	Mn	As	Ba
Bail, unfilt.	<0.005	<0.02	6.52	<0.05	0.16	<0.002	0.060
Bail, 0.45 um	<0.005	<0.02	0.04	<0.05	0.02	<0.002	0.012
Bail, 0.45 um	<0.005	<0.02	0.13	<0.05	0.02	<0.002	0.014
WISC–4							
CP1, unfilt.	<0.005	<0.02	2.0	<0.05	0.06	<0.002	0.175
CP1, unfilt.	<0.005	<0.02	2.0	<0.05	0.06	<0.002	0.175
CP1, 0.45 um	<0.005	<0.02	0.02	<0.05	0.03	<0.002	0.159
CP1, 0.45 um	<0.005	<0.02	0.02	<0.05	0.03	<0.002	0.159
BP, 0.45 um	<0.005	<0.02	0.03	<0.05	0.07	<0.002	0.163
BP, 0.45 um	<0.005	<0.02	0.04	<0.05	0.04	<0.002	0.168
BP, unfilt.	<0.005	<0.02	0.06	<0.05	0.04	<0.002	0.164
BP, unfilt.	<0.005	<0.02	0.07	<0.05	0.04	<0.002	0.164
CP2, unfilt.	<0.005	<0.02	0.59	<0.05	0.05	<0.002	0.179
CP2, unfilt.	<0.005	<0.02	0.56	<0.05	0.05	<0.002	0.171
CP2, 0.45 um	<0.005	<0.02	0.04	<0.05	0.04	<0.002	0.170
CP2, 0.45 um	<0.005	<0.02	0.06	<0.05	0.04	<0.002	0.170
Bail, unfilt.	<0.005	0.09	62.0	<0.05	1.15	0.008	0.819
Bail, unfilt.	<0.005	0.13	80.0	<0.05	1.56	0.008	0.566
Bail, 0.45 um	<0.005	<0.02	<0.01	<0.05	0.11	<0.002	0.189
Bail, 0.45 um	<0.005	<0.02	<0.01	<0.05	0.11	<0.002	0.192
NEV–1							
CP1, unfilt.	<0.005	<0.02	0.11	<0.05	0.73	0.14	0.027
CP1, unfilt.	<0.005	<0.02	0.10	<0.05	0.74	0.12	0.026
CP1, 0.45 um	<0.005	<0.02	0.08	<0.05	0.73	0.14	0.025
CP1, 0.45 um	<0.005	<0.02	0.14	<0.05	0.73	0.14	0.026
CP1, 5.0 um	<0.005	<0.02	0.11	<0.05	0.75	0.12	0.026
CP1, 5.0 um	<0.005	0.02	0.10	<0.05	0.75	0.14	0.026
BP, unfilt.	<0.005	<0.02	0.04	<0.05	0.73	0.12	0.027
BP, unfilt.	<0.005	<0.02	0.04	<0.05	0.72	0.13	0.027
BP, 0.45 um	<0.005	<0.02	0.04	<0.05	0.73	0.12	0.027
BP, 0.45 um	<0.005	<0.02	0.04	<0.05	0.73	0.12	0.027
BP, 5.0 um	<0.005	<0.02	0.04	<0.05	0.73	0.11	0.027
BP, 5.0 um	<0.005	<0.02	0.04	<0.05	0.73	0.11	0.027
CP2, unfilt.	<0.005	0.02	0.04	<0.05	0.74	0.16	0.027
CP2, unfilt.	<0.005	0.02	0.06	<0.05	0.74	0.16	0.027
CP2, 0.45 um	<0.005	<0.02	0.06	<0.05	0.74	0.14	0.026
CP2, 0.45 um	<0.005	<0.02	0.03	<0.05	0.74	0.15	0.026
CP2, 5.0 um	<0.005	0.02	0.05	<0.05	0.74	0.15	0.026
CP2, 5.0 um	<0.005	<0.02	0.05	<0.05	0.74	0.15	0.026
Bail, unfilt.	<0.005	<0.02	1.28	<0.05	0.79	0.14	0.043
Bail, unfilt.	<0.005	<0.02	1.47	<0.05	0.79	0.15	0.050
Bail, 0.45 um	<0.005	<0.02	0.04	<0.05	0.73	0.15	0.025

continued

TABLE C–1. TRACE METALS ANALYTICAL RESULTS (CONCENTRATIONS EXPRESSED AS MG/L)

Device/Filtration Type	Cd	Cr	Fe	Pb	Mn	As	Ni
Bail, 0.45 um	<0.005	<0.02	0.04	<0.05	0.74	0.16	0.026
Bail, 5.0 um	<0.005	0.04	0.10	<0.05	0.73	0.14	0.026
Bail, 5.0 um	<0.005	<0.02	0.04	<0.05	0.72	0.14	0.026
NEV–2							
CP1, unfilt.	<0.005	<0.02	0.06	<0.05	1.05	0.11	0.025
CP1, unfilt.	<0.005	<0.02	0.06	<0.05	1.06	0.11	0.024
CP1, 0.45 um	<0.005	<0.02	0.05	<0.05	1.07	0.10	0.025
CP1, 0.45 um	<0.005	<0.02	0.05	<0.05	1.09	0.11	0.025
BP, unfilt.	<0.005	<0.02	0.02	<0.05	1.06	0.08	0.026
BP, unfilt.	<0.005	<0.02	0.03	<0.05	1.05	0.08	0.026
BP, 0.45 um	<0.005	<0.02	0.02	<0.05	1.07	0.08	0.026
BP, 0.45 um	<0.005	<0.02	0.02	<0.05	1.07	0.08	0.025
CP2, unfilt.	<0.005	<0.02	0.02	<0.05	1.10	0.12	0.025
CP2, unfilt.	<0.005	0.02	0.06	<0.05	1.11	0.12	0.025
CP2, 0.45 um	<0.005	<0.02	0.05	<0.05	1.10	0.11	0.024
CP2, 0.45 um	<0.005	<0.02	0.02	<0.05	1.09	0.10	0.023
Bail, unfilt.	<0.005	0.06	14.1	<0.05	1.43	0.13	0.399
Bail, unfilt.	<0.005	0.05	13.8	<0.05	1.42	0.12	0.350
Bail, 0.45 um	<0.005	<0.02	0.03	<0.05	1.04	0.12	0.024
Bail, 0.45 um	<0.005	<0.02	0.05	<0.05	1.07	0.11	0.024
WASH–1							
CP1, unfilt.	<0.005	0.05	1.52	<0.05	0.17	0.006	0.05
CP1, unfilt.	<0.005	0.04	1.73	<0.05	0.13	0.007	0.03
CP1, 0.45 um	<0.005	<0.02	0.03	<0.05	0.08	0.006	0.01
CP1, 0.45 um	<0.005	<0.02	0.02	<0.05	0.08	0.005	0.02
BP, unfilt.	<0.005	<0.02	7.69	<0.05	0.19	0.008	0.02
BP, unfilt.	<0.005	<0.02	7.00	<0.05	0.18	0.008	0.02
BP, 0.45 um	<0.005	<0.02	<0.01	<0.05	0.06	0.006	<0.0
BP, 0.45 um	<0.005	<0.02	<0.01	<0.05	0.06	0.006	0.01
CP2, unfilt.	<0.005	0.19	67.6	<0.05	1.17	0.015	0.17
CP2, unfilt.	<0.005	0.19	68.2	<0.05	1.24	0.015	0.18
CP2, 0.45 um	<0.005	<0.02	0.02	<0.05	0.08	0.005	0.01
CP2, 0.45 um	<0.005	<0.02	<0.01	<0.05	0.08	0.005	0.02
Bail, unfilt.	<0.005	0.06	42.1	<0.05	0.90	0.020	0.09
Bail, unfilt.	<0.005	0.07	42.3	<0.05	0.90	0.020	0.09
Bail, 0.45 um	<0.005	<0.02	<0.01	<0.05	0.07	0.006	<0.01
Bail, 0.45 um	<0.005	<0.02	<0.01	<0.05	0.07	0.006	<0.01
WASH–2							
CP1, unfilt.	<0.005	<0.02	1.38	<0.05	0.03	<0.002	0.01
CP1, unfilt.	<0.005	<0.02	1.40	<0.05	0.03	<0.002	<0.01
CP1, 0.45 um	<0.005	<0.02	1.05	<0.05	0.03	<0.002	0.01
CP1, 0.45 um	<0.005	<0.02	1.10	<0.05	0.03	<0.002	<0.01

continued

TABLE C-1. TRACE METALS ANALYTICAL RESULTS (CONCENTRATIONS EXPRESSED AS MG/L)

Device/Filtration Type	Cd	Cr	Fe	Pb	Mn	As	Ni
CP1, 5.0 um	<0.005	<0.02	1.34	<0.05	0.03	<0.002	<0.01
CP1, 5.0 um	<0.005	<0.02	1.34	<0.05	0.03	<0.002	<0.01
BP, unfilt.	<0.005	<0.02	1.52	<0.05	0.03	<0.002	<0.01
BP, unfilt.	<0.005	<0.02	1.52	<0.05	0.03	<0.002	<0.01
BP, 0.45 um	<0.005	<0.02	1.31	<0.05	0.03	<0.002	<0.01
BP, 0.45 um	<0.005	<0.02	1.31	<0.05	0.03	<0.002	<0.01
CP2, unfilt.	<0.005	<0.02	1.42	<0.05	0.03	<0.002	<0.01
CP2, unfilt.	<0.005	<0.02	1.42	<0.05	0.03	<0.002	<0.01
CP2, 0.45 um	<0.005	<0.02	1.16	<0.05	0.03	<0.002	<0.01
CP2, 0.45 um	<0.005	<0.02	1.18	<0.05	0.03	<0.002	<0.01
Bail, unfilt.	<0.005	0.04	19.6	<0.05	0.18	0.004	0.05
Bail, unfilt.	<0.005	0.04	17.4	<0.05	0.19	0.003	0.05
Bail, 0.45 um	<0.005	<0.02	1.14	<0.05	0.03	0.002	<0.01
Bail, 0.45 um	<0.005	<0.02	1.12	<0.05	0.04	0.002	<0.01
WASH-3							
CP1, unfilt.	<0.005	<0.02	19.9	<0.05	2.97	0.007	0.04
CP1, unfilt.	<0.005	<0.02	20.9	<0.05	3.06	0.007	0.03
CP1, 0.45 um	<0.005	<0.02	20.1	<0.05	2.97	0.008	0.03
CP1, 0.45 um	<0.005	<0.02	20.1	<0.05	2.97	0.007	0.03
CP1, 5.0 um	<0.005	<0.02	20.6	<0.05	3.01	0.007	0.04
CP1, 5.0 um	<0.005	<0.02	20.3	<0.05	2.97	0.008	0.04
BP, unfilt.	<0.005	<0.02	19.1	<0.05	2.60	0.007	0.06
BP, unfilt.	<0.005	<0.02	18.9	<0.05	2.60	0.007	0.04
BP, 0.45 um	<0.005	<0.02	18.5	<0.05	2.56	0.008	0.04
BP, 0.45 um	<0.005	<0.02	18.2	<0.05	2.50	0.007	0.05
BP, 5.0 um	<0.005	<0.02	18.2	<0.05	2.48	0.007	0.05
BP, 5.0 um	<0.005	<0.02	18.5	<0.05	2.50	0.008	0.06
CP2, unfilt.	<0.005	<0.02	19.7	<0.05	2.81	0.006	0.05
CP2, unfilt.	<0.005	<0.02	19.4	<0.05	2.75	0.006	0.05
CP2, 0.45 um	<0.005	<0.02	16.3	<0.05	2.43	0.006	0.06
CP2, 0.45 um	<0.005	<0.02	17.3	<0.05	2.50	0.006	0.05
CP2, 5.0 um	<0.005	<0.02	18.7	<0.05	2.66	0.006	0.05
CP2, 5.0 um	<0.005	<0.02	18.5	<0.05	2.64	0.006	0.06
Bail, unfilt.	<0.005	<0.02	18.4	<0.05	2.64	0.006	0.04
Bail, unfilt.	<0.005	<0.02	19.0	<0.05	2.72	0.006	0.04
Bail, 0.45 um	<0.005	<0.02	18.5	<0.05	2.66	0.005	0.04
Bail, 0.45 um	<0.005	<0.02	18.5	<0.05	2.64	0.005	0.04
Bail, 5.0 um	<0.005	<0.02	18.4	<0.05	2.64	0.006	0.05
Bail, 5.0 um	<0.005	<0.02	18.4	<0.05	2.64	0.006	0.05

TABLE C-2. GROSS CHEMISTRY ANALYTICAL RESULTS (CONCENTRATIONS EXPRESSED AS MG/L)

Device / Filtration Type	EC	pH	Dissolved Solids	Si	Organic Carbon
WISC–1					
BP, unfilt.	2060	6.87	1012	26.1	7.4
BP, unfilt.	1950	6.90	1040	26.4	8.3
BP, 0.45 um	2040	6.81	1044	26.2	8.6
BP, 0.45 um	1920	6.84	982	26.2	8.2
Bail, 0.45 um	2030	6.88	1230	25.8	8.5
Bail, 0.45 um	2030	6.96	1267	25.7	7.5
WISC–2					
CP1, unfilt.	227	8.49	138	11.8	3.3
CP1, unfilt.	219	8.43	130	11.7	3.1
CP1, 0.45 um	214	8.79	128	12.0	4.4
CP1, 0.45 um	216	8.80	130	11.8	3.5
CP1, 5.0 um	216	8.78	126	11.7	3.1
CP1, 5.0 um	218	8.74	125	11.6	3.3
BP, unfilt.	204	8.76	128	11.7	3.0
BP, unfilt.	208	8.82	128	11.6	3.1
BP, 0.45 um	203	8.78	124	11.9	3.5
BP, 0.45 um	203	8.78	126	11.9	3.5
BP, 5.0 um	203	8.77	124	11.6	3.5
BP, 5.0 um	203	8.77	118	11.7	2.9

Device / Filtration Type	HCO3	CO3	Cl	SO4	NO3	Na	K	Ca	Mg
WISC–1									
BP, unfilt.	1430	<5	23.2	177	<0.01	16.4	1.66	312	126
BP, unfilt.	1410	<5	23.7	176	0.04	16.4	1.69	312	128
BP, 0.45 um	1420	<5	23.8	181	0.01	16.5	1.69	311	126
BP, 0.45 um	1410	<5	24.0	179	0.03	16.6	1.71	311	126
Bail, 0.45 um	1390	<5	23.6	161	<0.01	16.5	1.69	305	123
Bail, 0.45 um	1390	<5	23.8	162	<0.01	16.4	1.69	305	123
WISC–2									
CP1, unfilt.	125	3.2	7.5	2.03	0.02	39.9	0.81	6.66	3.05
CP1, unfilt.	125	2.2	6.4	1.53	0.1	40.3	0.81	6.57	3.05
CP1, 0.45 um	116	7.9	5.5	1.16	0.01	40.5	0.83	6.39	2.97
CP1, 0.45 um	111	10.4	5.2	1.14	<0.01	41.1	0.78	6.46	3.10
CP1, 5.0 um	113	9.4	5.7	1.25	0.01	40.7	0.81	6.57	3.02
CP1, 5.0 um	113	9.4	6.2	1.51	0.01	40.5	0.81	6.48	3.02
BP, unfilt.	115	8.5	4.0	0.95	0.02	38.9	0.78	6.39	2.99
BP, unfilt.	110	10.8	4.3	1.0	0.02	38.9	0.78	6.39	2.97
BP, 0.45 um	115	8.4	3.4	0.69	<0.01	38.9	0.76	6.21	2.94
BP, 0.45 um	117	6.9	3.4	0.67	<0.01	38.9	0.76	6.21	2.88
BP, 5.0 um	112	10.0	3.3	0.68	<0.01	38.9	0.78	6.21	2.91
BP, 5.0 um	112	9.6	3.3	0.69	<0.01	39.3	0.76	6.21	2.91

TABLE C-2. GROSS CHEMISTRY ANALYTICAL RESULTS CONT.

Device / Filtration Type	EC	pH	Dissolved Solids	Si	Organic Carbon
WISC–2					
CP2, unfilt.	204	8.07	126	11.5	3.1
CP2, unfilt.	205	8.13	128	11.5	3.1
CP2, 0.45 um	201	8.79	126	11.8	3.6
CP2, 0.45 um	201	8.78	121	11.8	3.4
CP2, 5.0 um	201	8.48	120	11.7	2.8
CP2, 5.0 um	201	8.50	124	11.6	2.9
Bail, unfilt.	217	8.74	154	11.6	3.1
Bail, unfilt.	217	8.70	156	11.6	3.1
Bail, 0.45 um	206	8.71	126	11.7	3.3
Bail, 0.45 um	206	8.70	127	11.6	3.5
WISC–3					
CP1, unfilt.	212	8.70	132	12.5	3.8
CP1, unfilt.	216	8.68	128	12.7	3.9
CP1, 0.45 um	216	8.72	131	13.2	4.3
CP1, 0.45 um	216	8.73	128	12.9	4.0
CP2, unfilt.	217	8.26	130	12.7	3.3
CP2, unfilt.	215	8.25	128	12.6	3.4
CP2, 0.45 um	216	8.73	132	12.9	3.7
CP2, 0.45 um	217	8.73	130	13.0	3.6

Device / Filtration Type	HCO3	CO3	Cl	SO4	NO3	Na	K	Ca	Mg
WISC–2									
CP2, unfilt.	131	<5	3.3	0.73	0.04	38.5	0.78	6.74	3.14
CP2, unfilt.	132	<5	3.3	0.70	0.02	38.9	0.78	6.66	3.11
CP2, 0.45 um	116	8.0	3.1	0.62	<0.01	39.1	0.76	6.21	2.88
CP2, 0.45 um	114	9.0	3.1	0.60	<0.01	38.7	0.76	6.21	2.91
CP2, 5.0 um	126	3.2	3.0	0.53	<0.01	38.5	0.78	6.21	2.91
CP2, 5.0 um	123	3.5	3.0	0.52	<0.01	39.1	0.78	6.30	2.94
Bail, unfilt.	124	8.8	3.3	0.72	<0.01	39.1	1.06	22.5	11.6
Bail, unfilt.	125	6.6	3.3	0.76	<0.01	39.2	1.17	21.2	10.9
Bail, 0.45 um	117	7.7	3.0	0.49	<0.01	38.9	0.80	6.30	2.98
Bail, 0.45 um	120	6.1	3.2	0.47	<0.01	38.8	0.78	6.30	2.95
WISC–3									
CP1, unfilt.	126	8.3	2.6	<0.5	0.01	39.2	0.97	6.73	4.10
CP1, unfilt.	128	7.7	2.6	<0.5	0.02	39.4	0.97	6.64	4.13
CP1, 0.45 um	125	8.9	2.7	<0.5	0.02	39.2	0.97	6.64	4.13
CP1, 0.45 um	127	8.4	2.8	<0.5	0.02	39.4	0.99	6.64	4.10
CP2, unfilt.	142	<5	2.6	0.5	<0.01	39.5	1.00	6.92	4.25
CP2, unfilt.	144	<5	2.7	<0.5	<0.01	39.7	1.00	6.92	4.22
CP2, 0.45 um	126	8.8	2.7	<0.5	<0.01	39.3	1.00	6.74	4.13
CP2, 0.45 um	127	7.9	2.7	<0.5	<0.01	39.7	1.00	6.66	4.16

TABLE C-2. GROSS CHEMISTRY ANALYTICAL RESULTS CONT.

Device / Filtration Type	EC	pH	Dissolved Solids	Si	Organic Carbon
WISC–3					
Bail, unfilt.	239	8.66	155	12.8	4.0
Bail, unfilt.	245	8.29	161	12.8	4.0
Bail, 0.45 um	217	8.52	128	13.0	4.1
Bail, 0.45 um	217	8.61	131	12.9	3.9
WISC–4					
CP1, unfilt.	1430	7.75	889	25.2	2.7
CP1, unfilt.	1430	7.77	911	25.8	2.7
CP1, 0.45 um	1430	7.80	895	25.8	4.1
CP1, 0.45 um	1440	7.81	889	30.0	3.1
BP, unfilt.	1420	7.34	874	26.6	2.6
BP, unfilt.	1430	7.60	822	26.9	2.6
BP, 0.45 um	1430	7.60	864	27.8	3.5
BP, 0.45 um	1430	7.68	870	27.5	3.3
CP2, unfilt.	1420	7.67	668	28.4	2.8
CP2, unfilt.	1350	7.65	749	28.5	2.8
CP2, 0.45 um	1420	7.48	840	28.5	3.5
CP2, 0.45 um	1420	7.48	812	28.6	3.0
Bail, unfilt.	1450	7.88	918	23.8	15.1
Bail, unfilt.	1450	7.84	933	24.7	14.7

Device / Filtration Type	HCO3	CO3	Cl	SO4	NO3	Na	K	Ca	Mg
WISC–3									
Bail, unfilt.	142	6.7	3.7	1.0	<0.01	39.8	1.28	31.2	16.4
Bail, unfilt.	158	<5	3.6	<1.0	<0.01	39.6	1.30	35.2	18.2
Bail, 0.45 um	135	4.0	2.7	<1.0	<0.01	39.2	0.97	6.73	4.33
Bail, 0.45 um	131	6.7	2.8	<1.0	<0.01	39.0	0.99	6.73	4.33
WISC–4									
CP1, unfilt.	860	<5	39.1	128	0.08	67.3	2.88	72.2	142
CP1, unfilt.	865	<5	39.1	145	0.10	68.3	2.95	72.2	142
CP1, 0.45 um	858	<5	38.9	141	0.07	66.3	2.78	68.8	141
CP1, 0.45 um	858	<5	39.2	141	0.11	66.3	2.80	68.5	142
BP, unfilt.	857	<5	38.3	147	0.03	69.6	3.18	68.3	141
BP, unfilt.	857	<5	38.9	147	0.04	68.6	3.18	67.9	140
BP, 0.45 um	856	<5	38.7	146	0.04	68.6	3.18	67.9	140
BP, 0.45 um	857	<5	38.8	146	0.05	68.6	3.20	67.9	140
CP2, unfilt.	854	<5	37.6	140	0.05	68.6	3.01	67.3	138
CP2, unfilt.	857	<5	37.9	140	0.04	68.4	3.01	67.0	138
CP2, 0.45 um	854	<5	38.0	140	0.05	68.8	3.03	65.8	137
CP2, 0.45 um	854	<5	38.2	147	0.04	68.4	3.03	66.2	136
Bail, unfilt.	132	75	39.6	149	0.10	69.0	3.50	220	179
Bail, unfilt.	1327	<5	40.1	147	0.10	69.0	3.47	141	143

TABLE C-2. GROSS CHEMISTRY ANALYTICAL RESULTS CONT.

Device / Filtration Type	EC	pH	Dissolved Solids	Si	Organic Carbon
WISC–4					
Bail, 0.45 um	1450	7.89	889	26.4	2.7
Bail, 0.45 um	1440	7.89	903	27.1	2.8
NEV–1					
CP1, unfilt.	22000	7.21	14950	100	6.1
CP1, unfilt.	22000	7.22	14960	104	6.3
CP1, 0.45 um	22000	7.23	14960	101	7.3
CP1, 0.45 um	22000	7.23	14980	102	8.0
CP1, 5.0 um	22000	7.32	15000	102	7.0
CP1, 5.0 um	22000	7.41	14980	102	5.9
BP, unfilt.	22000	7.22	14880	101	6.4
BP, unfilt.	22000	7.20	14950	101	7.7
BP, 0.45 um	22000	7.18	14930	102	6.5
BP, 0.45 um	22000	7.21	14960	101	6.2
BP, 5.0 um	22000	7.22	14890	102	6.6
BP, 5.0 um	22100	7.24	14940	102	6.8
CP2, unfilt.	22000	7.12	14890	101	6.7
CP2, unfilt.	22000	7.12	14930	100	7.1
CP2, 0.45 um	22000	7.19	14910	102	8.0
CP2, 0.45 um	22000	7.14	14930	101	7.5

Device / Filtration Type	HCO3	CO3	Cl	SO4	NO3	Na	K	Ca	Mg
WISC–4									
Bail, 0.45 um	857	<5	39.0	140	0.04	69.0	3.07	68.9	141
Bail, 0.45 um	857	<5	39.0	139	0.04	68.8	3.07	68.9	140
NEV–1									
CP1, unfilt.	415	<5	6320	2570	<0.01	4500	60.8	437	214
CP1, unfilt.	414	<5	6320	2560	<0.01	4480	60.6	434	212
CP1, 0.45 um	413	<5	6300	2550	0.01	4460	61.1	434	216
CP1, 0.45 um	415	<5	6310	2560	<0.01	4480	61.4	437	216
CP1, 5.0 um	415	<5	6300	2560	<0.01	4480	60.8	437	214
CP1, 5.0 um	413	<5	6300	2550	<0.01	4460	60.8	437	215
BP, unfilt.	415	<5	6220	2540	<0.01	4480	63.8	457	222
BP, unfilt.	414	<5	6310	2550	<0.01	4510	63.8	457	218
BP, 0.45 um	415	<5	6300	2540	<0.01	4500	63.8	457	220
BP, 0.45 um	416	<5	6290	2540	<0.01	4500	63.8	461	222
BP, 5.0 um	414	<5	6320	2550	<0.01	4520	63.8	457	222
BP, 5.0 um	415	<5	6300	2550	<0.01	4510	63.8	457	222
CP2, unfilt.	415	<5	6260	2560	<0.01	4550	64.1	457	218
CP2, unfilt.	415	<5	6320	2550	<0.01	4480	63.8	457	218
CP2, 0.45 um	414	<5	6310	2570	<0.01	4500	64.1	453	217
CP2, 0.45 um	414	<5	6280	2560	<0.01	4500	64.1	453	218

TABLE C-2. GROSS CHEMISTRY ANALYTICAL RESULTS CONT.

Device / Filtration Type	EC	pH	Dissolved Solids	Si	Organic Carbon
NEV–1					
CP2, 5.0 um	22000	7.22	14950	101	6.4
CP2, 5.0 um	22000	7.24	14930	101	6.7
Bail, unfilt.	22000	7.60	14930	101	7.4
Bail, unfilt.	22000	7.61	14900	102	8.1
Bail, 0.45 um	22000	7.63	14940	103	8.2
Bail, 0.45 um	22000	7.57	14900	102	8.1
Bail, 5.0 um	22000	7.72	14920	101	7.9
Bail, 5.0 um	22000	7.81	14900	101	7.5
NEV–2					
CP1, unfilt.	20600	7.40	14070	98.2	5.8
CP1, unfilt.	20600	7.41	14080	98.0	5.8
CP1, 0.45 um	20700	7.52	14030	98.6	6.1
CP1, 0.45 um	20600	7.59	14010	97.4	6.3
BP, unfilt.	20800	7.26	14100	97.7	5.7
BP, unfilt.	20800	7.31	14100	97.4	5.9
BP, 0.45 um	20800	7.23	14130	97.0	5.5
BP, 0.45 um	20800	7.27	14160	96.9	5.5

Device / Filtration Type	HCO3	CO3	Cl	SO4	NO3	Na	K	Ca	Mg
NEV–1									
CP2, 5.0 um	414	<5	6310	2530	<0.01	4470	64.4	457	217
CP2, 5.0 um	415	<5	6300	2540	<0.01	4480	64.1	457	218
Bail, unfilt.	421	<5	6150	2580	<0.01	4440	62.5	452	221
Bail, unfilt.	417	<5	6240	2470	<0.01	4470	62.3	452	221
Bail, 0.45 um	417	<5	6260	2580	<0.01	4450	62.3	441	215
Bail, 0.45 um	417	<5	6250	2520	<0.01	4480	62.3	441	218
Bail, 5.0 um	417	<5	6270	2570	<0.01	4490	62.3	441	216
Bail, 5.0 um	416	<5	6280	2570	<0.01	4470	62.0	441	216
NEV–2									
CP1, unfilt.	394	<5	5750	2640	<0.01	4170	55.0	416	19
7 CP1, unfilt.	394	<5	5760	2640	<0.01	4210	55.6	416	197
CP1, 0.45 um	394	<5	5770	2650	0.01	4190	55.0	416	197
CP1, 0.45 um	393	<5	5750	2640	0.01	4190	55.3	416	197
BP, unfilt.	395	<5	5800	2650	<0.01	4280	57.5	428	202
BP, unfilt.	396	<5	5780	2650	<0.01	4280	57.5	428	199
BP, 0.45 um	395	<5	5780	2640	0.01	4250	56.9	428	199
BP, 0.45 um	397	<5	5770	2630	0.01	4250	57.5	428	202

TABLE C-2. GROSS CHEMISTRY ANALYTICAL RESULTS CONT.

Device / Filtration Type	EC	pH	Dissolved Solids	Si	Organic Carbon
NEV–2					
CP2, unfilt.	20800	7.28	14120	98.1	6.1
CP2, unfilt.	20800	7.17	14180	97.7	6.0
CP2, 0.45 um	20700	7.17	14140	98.5	5.6
CP2, 0.45 um	20800	7.19	14100	97.8	5.4
Bail, unfilt.	20700	7.36	14140	96.9	5.7
Bail, unfilt.	20700	7.44	14170	97.2	5.8
Bail, 0.45 um	20700	7.49	14150	98.6	7.1
Bail, 0.45 um	20700	7.60	14150	98.0	7.1
WASH–1					
CP1, unfilt.	839	8.08	470	26.7	2.0
CP1, unfilt.	844	8.05	475	26.8	1.9
CP1, 0.45 um	841	8.04	468	26.9	2.9
CP1, 0.45 um	837	8.08	459	26.8	2.4
BP, unfilt.	867	8.17	466	25.9	2.0
BP, unfilt.	866	8.20	470	26.0	2.2
BP, 0.45 um	865	8.15	461	26.1	2.9
BP, 0.45 um	864	8.19	458	25.8	3.7

Device / Filtration Type	HCO3	CO3	Cl	SO4	NO3	Na	K	Ca	Mg
NEV–2									
CP2, unfilt.	396	<5	5800	2650	<0.01	4300	57.8	428	199
CP2, unfilt.	395	<5	5790	2630	<0.01	4260	57.5	428	202
CP2, 0.45 um	397	<5	5820	2650	<0.01	4280	57.5	428	198
CP2, 0.45 um	396	<5	5810	2650	<0.01	4250	57.8	428	200
Bail, unfilt.	412	<5	5660	2690	<0.01	4200	56.1	481	205
Bail, unfilt.	417	<5	5750	2670	<0.01	4220	56.1	488	207
Bail, 0.45 um	395	<5	5790	2680	0.01	4220	55.3	419	197
Bail, 0.45 um	395	<5	5830	2680	0.01	4220	55.0	416	199
WASH–1									
CP1, unfilt.	492	<5	39.9	22.0	0.02	69.8	3.81	48.2	46.4
CP1, unfilt.	492	<5	40.2	21.9	0.02	69.8	3.78	48.6	45.7
CP1, 0.45 um	488	<5	40.4	22.0	0.02	70.6	3.74	48.4	46.3
CP1, 0.45 um	489	<5	40.0	22.1	0.02	69.8	3.74	48.2	45.7
BP, unfilt.	514	<5	38.4	22.0	<0.01	72.7	4.45	52.9	50.0
BP, unfilt.	513	<5	38.9	22.2	<0.01	72.3	4.43	52.9	49.
BP, 0.45 um	507	<5	39.2	22.8	<0.01	71.4	4.30	51.3	47.6
BP, 0.45 um	508	<5	39.2	22.8	<0.01	71.9	4.28	51.3	47.3

TABLE C-2. GROSS CHEMISTRY ANALYTICAL RESULTS CONT.

Device / Filtration Type	EC	pH	Dissolved Solids	Si	Organic Carbon
WASH–1					
CP2, unfilt.	814	8.13	475	26.0	1.9
CP2, unfilt.	834	8.15	466	26.1	2.0
CP2, 0.45 um	837	8.12	467	26.5	2.7
CP2, 0.45 um	837	8.15	471	25.9	2.6
Bail, unfilt.	867	8.17	458	25.5	2.4
Bail, unfilt.	877	8.14	474	25.7	2.4
Bail, 0.45 um	883	8.16	486	26.4	4.1
Bail, 0.45 um	863	8.14	483	25.9	2.8
WASH–2					
CP1, unfilt.	96.7	6.86	92	17.5	13.2
CP1, unfilt.	99.7	6.79	88	17.6	13.3
CP1, 0.45 um	99.7	6.65	82	17.6	13.7
CP1, 0.45 um	101	6.52	85	17.4	13.5
CP1, 5.0 um	100	6.51	88	17.3	13.0
CP1, 5.0 um	100	6.46	86	17.3	13.2
BP, unfilt.	100	6.60	86	17.2	12.7
BP, unfilt.	99.0	6.58	87	17.4	12.3
BP, 0.45 um	99.3	6.57	82	17.3	12.9
BP, 0.45 um	99.0	6.52	82	17.3	12.9

Device / Filtration Type	HCO3	CO3	Cl	SO4	NO3	Na	K	Ca	Mg
WASH–1									
CP2, unfilt.	517	<5	40.3	25.0	<0.01	69.4	5.06	74.1	52.8
CP2, unfilt.	514	<5	39.3	25.5	<0.01	70.1	5.08	74.6	52.
CP2, 0.45 um	483	<5	40.8	24.7	<0.01	69.4	4.18	52.9	43.9
CP2, 0.45 um	484	<5	40.3	24.5	<0.01	69.3	4.18	52.4	43.6
Bail, unfilt.	536	<5	37.8	22.8	0.01	72.7	4.95	66.1	56.4
Bail, unfilt.	542	<5	38.2	21.9	0.01	72.8	4.95	65.6	56.6
Bail, 0.45 um	527	<5	38.4	21.4	0.02	70.6	4.24	49.2	47.1
Bail, 0.45 um	510	<5	38.4	22.2	0.02	71.4	4.26	49.2	47.3
WASH–2									
CP1, unfilt.	39.5	<5	3.5	11.82	0.05	6.34	0.62	6.36	5.27
CP1, unfilt.	38.4	<5	3.7	11.91	0.04	6.29	0.62	6.36	5.25
CP1, 0.45 um	38.1	<5	3.6	11.86	0.04	6.29	0.62	6.27	5.20
CP1, 0.45 um	39.3	<5	3.6	11.93	0.04	6.17	0.61	6.17	5.13
CP1, 5.0 um	39.6	<5	3.7	11.91	0.04	6.29	0.62	6.27	5.19
CP1, 5.0 um	38.8	<5	3.8	11.9	0.04	6.29	0.62	6.27	5.27
BP, unfilt.	37.1	<5	3.6	12.1	0.03	6.10	0.64	6.60	5.25
BP, unfilt.	38.1	<5	3.7	12.1	0.03	6.14	0.64	6.60	5.30
BP, 0.45 um	37.9	<5	3.6	12.0	0.03	6.10	0.64	6.50	5.22
BP, 0.45 um	38.7	<5	3.6	12.0	0.03	6.02	0.64	6.50	5.09

TABLE C-2. GROSS CHEMISTRY ANALYTICAL RESULTS CONT.

Device / Filtration Type	EC	pH	Dissolved Solids	Si	Organic Carbon
WASH-2					
CP2, unfilt.	101	6.68	85	17.2	12.7
CP2, unfilt.	99.0	6.65	88	17.4	13.4
CP2, 0.45 um	98.4	6.64	84	17.4	12.0
CP2, 0.45 um	98.6	6.67	84	17.5	12.1
Bail, unfilt.	104	6.70	144	17.0	21.6
Bail, unfilt.	104	6.72	151	17.2	19.7
Bail, 0.45 um	98.5	6.64	84	17.1	14.1
Bail, 0.45 um	98.5	6.69	85	17.0	12.7
WASH-3					
CP1, unfilt.	645	6.56	398	41.0	22.3
CP1, unfilt.	657	6.54	398	41.4	20.4
CP1, 0.45 um	665	6.59	383	42.3	23.5
CP1, 0.45 um	650	6.62	381	42.0	22.6
CP1, 5.0 um	635	6.60	391	41.0	22.2
CP1, 5.0 um	648	6.66	394	41.3	20.8
BP, unfilt.	608	6.90	374	40.5	22.9
BP, unfilt.	608	7.08	376	40.6	23.4

Device / Filtration Type	HCO3	CO3	Cl	SO4	NO3	Na	K	Ca	Mg
WASH-2									
CP2, unfilt.	39.2	<5	3.6	12.3	0.03	6.10	0.64	6.50	5.20
CP2, unfilt.	38.7	<5	3.7	12.1	0.03	6.10	0.64	6.50	5.25
CP2, 0.45 um	37.8	<5	3.5	12.1	0.03	6.18	0.63	6.50	5.16
CP2, 0.45 um	37.5	<5	3.5	12.0	0.03	6.18	0.64	6.61	5.16
Bail, unfilt.	43.7	<5	4.8	14.1	0.03	7.48	1.63	15.7	11.4
Bail, unfilt.	44.3	<5	4.8	18.40	0.03	7.24	1.51	14.2	10.7
Bail, 0.45 um	38.5	<5	3.6	12.0	0.04	7.24	0.74	7.44	4.13
Bail, 0.45 um	39.1	<5	3.6	12.0	0.04	7.40	0.74	7.44	4.03
WASH-3									
CP1, unfilt.	366	<5	8.2	28.5	4.21	19.5	17.4	52.1	30.5
CP1, unfilt.	372	<5	8.3	28.2	4.08	19.4	17.6	52.0	29.
7 CP1, 0.45 um	378	<5	8.1	27.6	3.84	19.1	17.1	52.0	29.6
CP1, 0.45 um	367	<5	7.9	28.4	4.06	19.0	17.2	52.0	29.7
CP1, 5.0 um	355	<5	8.3	29.1	4.28	18.6	17.1	52.0	29.3
CP1, 5.0 um	368	<5	8.2	28.1	4.00	18.3	17.0	51.8	29.6
BP, unfilt.	340	<5	8.1	27.1	2.77	16.8	15.8	49.1	29.2
BP, unfilt.	339	<5	8.2	27.1	2.38	16.5	15.8	49.1	29.0

TABLE C-2. GROSS CHEMISTRY ANALYTICAL RESULTS CONT.

Device / Filtration Type	EC	pH	Dissolved Solids	Si	Organic Carbon
WASH–3					
BP, 5.0 um	586	7.00	361	40.3	23.8
BP, 5.0 um	596	6.80	368	40.5	22.8
CP2, unfilt.	624	6.88	385	40.5	22.4
CP2, unfilt.	623	6.98	387	41.0	22.4
CP2, 0.45 um	611	6.98	370	41.7	22.6
CP2, 0.45 um	624	6.92	388	42.0	22.7
CP2, 5.0 um	601	6.95	375	40.8	23.1
CP2, 5.0 um	607	6.93	373	40.5	23.6
Bail, unfilt.	615	6.85	373	40.0	24.9
Bail, unfilt.	618	6.89	377	40.5	24.9
Bail, 0.45 um	628	7.05	366	41.0	23.9
Bail, 0.45 um	623	6.91	353	40.9	24.8
Bail, 5.0 um	612	6.96	373	40.9	25.0
Bail, 5.0 um	605	7.10	370	40.2	23.3

Device / Filtration Type	HCO3	CO3	Cl	SO4	NO3	Na	K	Ca	Mg
WASH–3									
BP, 0.45 um	328	<5	7.8	28.4	2.56	16.5	15.7	48.2	29.1
BP, 0.45 um	335	<5	7.8	27.7	2.37	16.4	15.5	48.2	28.8
BP, 5.0 um	322	<5	8.1	28.5	3.00	16.4	15.5	48.2	28.9
BP, 5.0 um	331	<5	8.3	27.9	2.75	16.4	15.7	48.2	28.9
CP2, unfilt.	351	<5	8.1	27.3	3.30	17.5	16.5	51.2	29.2
CP2, unfilt.	352	<5	8.1	27.4	3.86	17.3	16.5	50.8	29.3
CP2, 0.45 um	341	<5	7.8	27.9	3.07	17.0	15.2	47.8	27.9
CP2, 0.45 um	353	<5	8.0	27.0	3.56	17.2	15.7	49.5	28.6
CP2, 5.0 um	335	<5	8.2	28.2	3.68	16.9	15.9	49.5	28.9
CP2, 5.0 um	338	<5	8.3	27.9	2.75	16.9	15.9	49.5	28.6
Bail, unfilt.	346	<5	8.2	27.8	1.74	17.2	15.2	47.8	28.0
Bail, unfilt.	347	<5	8.3	27.7	2.02	17.1	15.7	48.6	28.8
Bail, 0.45 um	352	<5	7.9	27.5	2.34	17.0	15.6	48.2	28.8
Bail, 0.45 um	345	<5	7.8	27.9	2.15	16.8	15.7	48.2	28.8
Bail, 5.0 um	340	<5	8.4	28.0	2.26	16.8	15.7	48.2	28.9
Bail, 5.0 um	333	<5	8.2	28.2	2.39	16.8	15.7	48.6	28.8

APPENDIX D
Results of Statistical Analysis

TABLE D–1. RESULTS OF STATISTICAL ANALYSIS

Device Numbering

1 = CP1
2 = BP
3 = CP2
4 = Bailer

Filtration Method Numbering

1 = Unfiltered
2 = 0.45 μm filtered

Well Numbering

1 = WISC–2
3 = WISC–4
4 = NEV–1
6 = WASH–1
7 = WASH–2
9 = WASH–3
5 = NEV–2

#3 Ba 4 Wells, 4 Devices, 2 Filtration Methods

Table of Means (log transformed)

Device	Ba
1	–3.44
2	–3.42
3	–3.43
4	–2.64

Filter	Ba
1	–3.04
2	–3.42

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	3	67.0096	22.3365		
Devices	3	7.4962	2.4987	12.3	.0001
Filter	1	2.2720	2.2720	11.1	.0032
D x F	3	6.0764	0.0255	9.9	.0003
Exp. Error	21	4.2794	0.2038		
Samp. Error	32	0.1179	0.0037		
Total	63	87.2515			

#4 Ni 3 Wells, 4 Devices, 2 Filtration Methods

Table of Means (log transformed)

Device	Ni
1	–3.93
2	–3,98
3	–3,52
4	–3.51

Filter	Ni
1	–3.39
2	–4.07

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	2	12.5101	6.2550		
Devices	3	2.3317	0.7772	0.97	.43
Filter	1	5.5574	5.5574	6.90	.0199
D x F	3	1.8784	0.6261	0.77	.53
Exp. Error	14	11.2685	0.8049		
Samp. Error	24	0.7777	0.0324		
Total	47	34.3238			

TABLE D–1. RESULTS OF STATISTICAL ANALYSIS CONT.

#6 Ba 4 Wells, 3 Devices, 2 Filtration Methods

Table of Means (log transformed)

Device	Ba
1	–3.4363
2	–3.4200
3	–3.4284

Filter	Ba
1	–3.4177
2	–3.4388

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	3	50.3986	16.7995		
Devices	2	0.0021	0.0011	0.65	.54
Filter	1	0.0053	0.0053	3.24	.093
D x F	2	0.0021	0.0010	0.63	.55
Exp. Error	14	0.0231	0.0016		
Samp. Error	24	0.0055	0.0002		
Total	47	50.4367			

#6 Ni 3 Wells, 3 Devices, 2 Filtration Methods

Table of Means (log transformed)

Device	Ni
1	–3.9316
2	–3.9752
3	–3.5188

Filter	Ni
1	–3.5663
2	–4.0507

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	2	13.06333	6.53167		
Devices	2	1.52237	0.76118	1.8	.21
Filter	1	2.11185	2.11185	5.1	.048
D x F	2	0.49371	0.24686	0.6	.94
Exp. Error	10	4.12528	0.41253		
Samp. Error	18	0.77766	0.04320		
Total	35	25.41991			

#8 Ba 4 Wells, 4 Devices, Unfiltered Samples Only

Table of Means (log transformed)

Device	Ba
1	–3.4221
2	–3.4187
3	–3.4123
4	–1.9159

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	3	34.476204	11.492067		
Devices	3	13.531530	4.510510	11.38	0.002
Exp. Error	9	3.567998	0.396444		
Samp. Error	16	0.110944	0.006934		
Total	31	51.686676			

TABLE D–1. RESULTS OF STATISTICAL ANALYSIS CONT.

#8 Ni 3 Wells, 4 Devices, Unfiltered Samples Only

Table of Means (log transformed)

Device	Ni
1	–3.7397
2	–3.8444
3	–3.1148
4	–2.8742

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	2	8.27328	4.13664		
Devices	3	4.02345	1.34115	1.47	0.313
Exp. Error	6	5.45940	0.90990		
Samp. Error	12	0.25569	0.02131		
Total	23	18.01181			

#8 Fe 7 Wells, 4 Devices, Unfiltered Samples Only

Table of Means (log transformed)

Well	Fe
1	–1.6597
3	0.4144
4	–2.0435
5	–1.8125
6	2.6092
7	1.0037
8	2.9653

Device	Fe
1	–0.5061
2	–0.9954
3	–0.2283
4	2.5737

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	6	213.470	35.578		
Devices	3	108.433	36.144	10.41	0.000
Exp. Error	18	62.502	3.472		
Samp. Error	28	0.852	0.030		
Total	55	385.257			

#8 Mn 7 Wells, 4 Devices, Unfiltered Samples Only

Table of Means (log transformed)

Well	Mn
1	–3.9310
3	–2.1839
4	–0.2916
5	0.1403
6	0.8783
7	–3.0519
8	–1.0168

Device	Mn
1	–1.6622
2	–1.7616
3	–1.4429
4	–0.3788

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	6	155,2640	25.8773		
Devices	3	16.9783	5.6594	5.31	0.008
Exp. Error	18	19.1922	1.0662		
Samp. Error	28	0.3333	0.0119		
Total	55	191,7678			

TABLE D–1. RESULTS OF STATISTICAL ANALYSIS CONT.

#8 As 7 Wells, 4 Devices, Unfiltered Samples Only

Table of Means (log transformed)

Well	As
1	−6.2146
3	−5.8680
4	−1.9719
5	−2.2334
6	−4.4947
7	−6.0773
8	−5.0389

Device	As
1	−4.6993
2	−4.7200
3	−4.5589
4	−4.2497

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	6	152.7663	25.4610		
Devices	3	1.9773	0.6591	3.50	0.037
Exp. Error	18	3.3941	0.1886		
Samp. error	28	0.0739	0.0026		
Total	55	158.2116			

#7 Fe 7 Wells, 4 Devices, 2 Filtration Methods, Omit 4,1

Table of Means (log transformed)

Device	Filter	Fe
1	1	−0.5061
1	2	−2.0565
2	1	−0.9954
2	2	−2.2037
3	1	−0.2283
3	2	−2.2166
4	2	−2.4637

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	6	470.107	78.351		
Treatment	6	71.433	11.905	2.86	0.022
Exp. Error	36	149.663	4.157		
Samp. Error	49	2.196	0.045		
Total	97	693.398			

#7 Mn 7 Wells, 4 Devices, 2 Filtration Methods, Omit 4,1

Table of Means (log transformed)

Device	Filter	Mn
1	1	−1.6622
1	2	−1.8990
2	1	−1.7616
2	2	−1.8833
3	1	−1.4429
3	2	−1.8807
4	2	−1.6811

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	6	351.7712	58.6285		
Treatment	6	2.2922	0.3820	1.04	0.418
Exp. Error	36	13.2671	0.3685		
Samp. Error	49	0.7200	0.0147		
Total	97	368.0506			

TABLE D–1. RESULTS OF STATISTICAL ANALYSIS CONT.

#7 As 7 Wells, 4 Devices, 2 Filtration Methods, Omit 4,1

Table of Means (log transformed)

Device	Filter	As
1	1	–4.6993
1	2	–4.7086
2	1	–4.7200
2	2	–4.7573
3	1	–4.5589
3	2	–4.7492
4	2	–4.7267

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	6	283.8582	47.3097		
Treatment	6	0.3745	0.0624	1.12	0.372
Exp. Error	36	2.0123	0.0559		
Samp. Error	49	0.0787	0.0016		
Total	97	286.3238			

#2 Fe 7 Wells, 4 Devices, 2 Filtration Methods

Table of Means (log transformed)

Device	Fe
1	–1.2813
2	–1.5995
3	–1.2224
4	0.0550

Filter	Fe
1	0.2110
2	–2.2351

Device	Filter	Fe
1	1	–0.5061
1	2	–2.0565
2	1	–0.9954
2	2	–2.2037
3	1	–0.2283
3	2	–2.2166
4	1	2.5737
4	2	–2.4637

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	6	436.533	72.755		
Devices	3	44.817	14.939	3.05	.039
Filter	1	167.531	167.531	34.16	< .001
D x F	3	64.813	21.604	4.41	.0087
Exp. Error	42	205.953	4.904		
Samp. Error	56	2.248	0.040		
Total	111	921.895			

TABLE D–1. RESULTS OF STATISTICAL ANALYSIS CONT.

#2 Mn 7 Wells, 4 Devices, 2 Filtration Methods

Table of Means (log transformed)

Device	Mn
1	–1.7806
2	–1.8224
3	–1.6618
4	–1.0300

Filter	Mn
1	–1.3114
2	–1.8360

Device	Filter	Mn
1	1	–1.6622
1	2	–1.8990
2	1	–1.7616
2	2	–1.8833
3	1	–1.4429
3	2	–1.8807
4	1	–0.3788
4	2	–1.6811

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	6	351.272	58.545		
Devices	3	11.427	3.809	5.31	0.0034
Filter	1	7.707	7.707	10.75	0.0021
D x F	3	6.002	2.001	2.79	0.052
Exp. Error	42	30.122	0.717		
Samp. Error	56	0.773	0.014		
Total	111	407.303			

#2 As 7 Wells, 4 Devices, 2 Filtration Methods

Table of Means (log transformed)

Device	As
1	–4.7044
2	–4.7386
3	–4.6541
4	–4.4882

Filter	As
1	–4.5570
2	–4.7357

Device	Filter	As
1	1	–4.6993
1	2	–4.7096
2	1	–4.7200
2	2	–4.7573
3	1	–4.5589
3	2	–4.7492
4	1	–4.2497
4	2	–4.7267

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	6	314.711	52.452		
Devices	3	1.035	0.345	2.66	0.060
Filter	1	0.894	0.894	6.89	0.012
D x F	3	0.962	0.321	2.47	0.075
Exp. Error	42	5.448	0.130		
Samp. Error	56	0.126	0.002		
Total	111	323.176			

TABLE D–1. RESULTS OF STATISTICAL ANALYSIS CONT.

#5 Fe 7 Wells, Devices 1–3 Only, 2 Filtration Methods

Table of Means (log transformed)

Device	Fe
1	–1.2813
2	–1.5995
3	–1.2224

Filter	Fe
1	–0.5766
2	–2.1589

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	6	390.048	65.008		
Devices	2	2.305	1.152	0.27	0.77
Filter	1	52.576	52.576	12.27	0.0015
D x F	2	2.140	1.070	0.25	0.78
Exp. Error	30	128.530	4.284		
Samp. Error	42	2.066	0.049		
Total	83	577.666			

#5 Mn 7 Wells, Devices 1–3 Only, 2 Filtration Methods

Table of Means (log transformed)

Device	Mn
1	–1.7806
2	–1.8224
3	–1.6618

Filter	Mn
1	–1.6222
2	–1.8877

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	6	309.0407	51.5068		
Devices	2	0.3890	0.1945	0.55	0.58
Filter	1	1.4796	1.4786	4.15	0.0505
D x F	2	0.3581	0.1791	0.50	0.61
Exp. Error	30	10.6942	0.3565		
Samp. Error	42	0.4378	0.0104		
Total	83	322.3995			

#5 As 7 Wells, Devices 1–3 Only, 2 Filtration Methods

Table of Means (log transformed)

Device	As
1	–4.7044
2	–4.4386
3	–4.6541

Filter	As
1	–4.6594
2	–4.7387

Analysis of Variance Table

Source	df	SS	MS	F	P
Wells	6	240.3703	40.0617		
Devices	2	0.1013	0.0507	0.87	0.43
Filter	1	0.1321	0.1321	2.27	0.14
D x F	2	0.1320	0.0660	1.14	0.33
Exp. Error	30	0.7428	0.0581		
Samp. Error	42	0.0729	0.0017		
Total	83	242.5513			

TABLE D–1. RESULTS OF STATISTICAL ANALYSIS CONT.

#9 Major Cations 7 Wells, 4 Devices, 2 Filtration Methods

Table of Means

Well	Na	K	Ca	Mg
1	78.6	1.65	16.67	8.05
3	136.7	6.17	164.85	285.00
4	8972.5	125.57	897.50	435.75
5	8471.2	112.93	861.50	399.63
6	141.8	8.68	110.74	97.37
7	12.9	1.52	15.28	11.59
8	35.0	32.28	99.35	58.12

Device N	a	K	Ca	Mg
1	2535.1	40.449	295.75	182.12
2	2561.4	41.660	305.03	184.88
3	2565.8	41.915	307.39	182.84
4	2536.9	41.003	329.48	190.46

Filter	Na	K	Ca	Mg
1	2552.0	41.461	318.84	187.62
2	2547.7	41.053	299.99	182.53

Device	Filter	Na	K	Ca	Mg
1	1	2538.1	40.469	296.32	181.85
1	2	2532.2	40.429	295.17	182.39
2	1	2565.2	41.754	305.17	185.20
2	2	2557.6	41.566	304.89	184.56
3	1	2570.1	42.171	311.63	184.80
3	2	2561.5	41.659	303.16	180.87
4	1	2534.4	41.449	362.24	198.63
4	2	2539.4	40.557	296.73	182.30

Analysis of Variance for Na

Source	df	SS	MS	F	P
Well	6	854425088	142404192		
Devices	3	10803	3601	3.70	1.019
Filter	1	259	259	0.27	0.608
D X F	3	418	139	0.14	0.933
Error	42	40887	974		
Total	55	854477504			

Analysis of Variance for K

Source	df	SS	MS	F	P
Well	6	142132	23689		
Devices	3	18	6	2.75	0.055
Filter	1	2	2	1.05	0.312
D X F	3	1	0	0.22	0.879
Error	42	94	2		
Total	55	142248			

Analysis of Variance for Ca

Source	df	SS	MS	F	P
Well	6	7418818	1236470		
Devices	3	8581	2860	2.95	0.044
Filter	1	4977	4977	5.13	0.029
D X F	3	10303	3434	3.54	0.023
Error	42	40757	970		
Total	55	7483436			

Analysis of Variance for Mg

Source	df	SS	MS	F	P
Well	0.0026	1632763	272127		
Devices	3	600	200	6.08	0.002
Filter	1	363	363	11.03	0.002
D X F	3	627	209	6.36	0.001
Error	42	1381	33		
Total	55	1635734			

TABLE D–1. RESULTS OF STATISTICAL ANALYSIS CONT.

#9 Major Anions 7 Wells, 4 Devices, 2 Filtration Methods

Table of Means

Well	HC03	C1	S04	N03
1	239.1	8	1.8	0.0400
3	1831.9	78	285.4	0.1255
4	830.9	12555	5110.0	0.0200
5	795.1	11551	5305.0	0.0200
6	1014.5	79	45.7	0.0275
7	78.2	8	25.1	0.0688
8	701.5	16	55.4	6.0388

Device	HC03	C1	S04	N03
1	767.81	3476.3	1544.2	1.2157
2	761.63	3473.0	1541.3	0.7529
3	764.44	3483.0	1546.2	1.0207
4	843.97	3450.2	1550.2	0.6321

Filter	HC03	C1	S04	N03
1	806.00	3463.8	1545.0	0.91679
2	762.92	3477.4	1546.0	0.89393

Device	Filter	HC03	C1	S04	N03
1	1	770.27	3478.0	1544.4	1.2514
1	2	765.34	3474.6	1544.0	1.1800
2	1	762.89	3470.9	1544.1	0.7686
2	2	760.37	3475.1	1538.4	0.7371
3	1	772.41	3479.3	1543.0	1.0614
3	2	756.47	3486.6	1549.5	0.9800
4	1	918.43	3426.9	1548.6	0.5857
4	2	769.51	3473.4	1551.9	0.6786

Analysis of Variance for HC03

Source	df	SS	MS	F	P
Well	6	15642300	2607050		
Devices	3	66372	22124	1.44	0.245
Filter	1	25976	25976	1.69	0.201
D X F	3	52635	17545	1.14	0.343
Error	42	645367	15366		
Total	55	16432651			

Analysis of Variance for C1

Source	df	SS	MS	F	P
Well	6	1654049536	275674912		
Devices	3	8523	2841	1.90	0.144
Filter	1	2609	2609	1.74	0.194
D X F	3	5246	1749	1.17	0.333
Error	42	62806	1495		
Total	55	1654128768			

Analysis of Variance for S04

Source	df	SS	MS	F	P
Well	6	300164384	50027396		
Devices	3	595	198	0.62	0.608
Filter	1	12	12	0.04	0.847
D X F	3	284	95	0.29	0.829
Error	42	13498	321		
Total	55	300178752			

Analysis of Variance for NO3

Source	df	SS	MS	F	P
Well	6	246	41		
Devices	3	3	1	2.42	0.079
Filter	1	0	0	0.02	0.893
D X F	3	0	0	0.06	0.982
Error	42	17	0		
Total	55	266			

TABLE D–1. RESULTS OF STATISTICAL ANALYSIS CONT.

#9 Other Parameters 7 Wells, 4 Devices, 2 Filtration Methods

Table of Means

Well	EC	pH	TDS	Si	TOC
1	419	17.284	262	23.44	6.700
3	2855	15.391	1716	53.95	9.000
4	44000	14.585	29862	203.00	14.450
5	41450	14.711	28229	195.50	11.925
6	1704	16.265	938	52.38	5.113
7	200	13.310	186	34.64	27.850
8	1249	13.711	754	82.21	46.213

Device	ED	pH	TDS	Si	TOC
1	13106	14.988	8852.1	92.664	16.450
2	13143	15.010	8843.4	91.879	16.314
3	13123	14.884	8822.9	92.564	16.229
4	13130	15.265	8880.0	91.529	20.293

Filter	ED	pH	TDS	Si	TOC
1	13125	14.997	8851.6	91.671	17.600
2	13126	15.076	8847.5	92.646	17.043

Device	Filter	HC03	C1	S04	N03
1	1	13098	14.937	8864.1	15.557
1	2	13113	15.039	8840.0	17.343
2	1	13144	15.006	8834.4	16.071
2	2	13141	15.004	8852.3	16.557
3	1	13125	14.811	8811.0	16.071
3	2	13121	14.957	8834.7	16.386
4	1	13131	15.234	8896.9	22.700
4	2	13128	15.296	8863.1	17.886

Analysis of Variance for EC

Source	df	SS	MS	F	P
Well	6	1.9688E+10	3281361408		
Devices	3	9922	3307	0.76	0.525
Filter	1	23	23	0.01	0.943
D X F	3	904	301	0.07	0.976
Error	42	183592	4371		
Total	55	1.9688E+10			

Analysis of Variance for pH

Source	df	SS	MS	F	P
Well	6	94	16		
Devices	3	1	0	3.87	0.016
Filter	1	0	0	0.93	0.340
D X F	3	0	0	0.13	0.944
Error	42	4	0		
Total	55	99			

Analysis of Variance for TDS

Source	df	SS	MS	F	P
Well	6	9159377920	1526562944		
Devices	3	23582	7861	1.67	0.187
Filter	1	232	232	0.05	0.825
D X F	3	8871	2957	0.63	0.600
Error	42	197297	4698		
Total	55	9159607296			

Analysis of Variance for Si

Source	df	SS	MS	F	P
Well	6	273105	45517		
Devices	3	13	4	2.54	0.069
Filter	1	13	13	8.09	0.007
D X F	3	3	1	0.59	0.627
Error	42	69	2		
Total	55	273203			

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