

**CHEMICAL AND STABLE-ISOTOPE DATA FROM AN
EXPERIMENT TO EXAMINE TEMPORAL VARIABILITY
IN WATER SAMPLES FROM SCREENED WELLS
ON CAPE COD, MASSACHUSETTS, 1994**

**By Thomas E. Reilly, Denis R. LeBlanc, Kimberly W. Bussey,
Terry B. Councell, Richard L. Smith and John Karl Böhlke**

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CONVERSION FACTORS, VERTICAL DATUM, AND ABBREVIATED WATER-QUALITY UNITS

	Multiply	By	To Obtain
	inch (in.)	25.4	millimeter (mm)
	foot (ft)	0.3048	meter (m)
	mile (mi)	1.609	kilometer (km)
	square foot (ft ²)	0.0929	square meter (m ²)
	acre	0.4047	square hectometer (hm ²)
	gallon (gal)	3.785	liter (L)
	cubic foot per second (ft ³ /s)	0.02832	cubic meter per second (m ³ /s)

Temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) by use of the following equation:

$$^{\circ}\text{F} = 1.8(^{\circ}\text{C}) + 32$$

Sea Level: In this report “sea level” refers to the National Geodetic Vertical Datum of 1929 (NGVD of 1929) - a geodetic datum derived from a general adjustment of the first-order level nets of both the United States and Canada, formerly called Sea Level Datum of 1929.

Abbreviated water-quality units used in this report: Chemical concentrations and water temperature are given in metric units. Chemical concentration is given in milligrams per liter (mg/L) or micrograms per liter (µg/L). Milligrams per liter is a unit expressing the concentration of chemical constituents in solution as weight (milligrams) of solute per unit volume (liter) of water. One thousand micrograms per liter is equivalent to one milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as concentrations in parts per million.

Specific conductance of water is expressed in microsiemens per centimeter at 25 degrees Celsius (µS/cm). This unit is equivalent to micromhos per centimeter at 25 degrees Celsius (µmho/cm), formerly used by the U.S. Geological Survey.

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ABSTRACT

An experiment was designed to evaluate the changing chemical composition of the water pumped from a well screened in a physically and chemically heterogeneous aquifer. Well F453-63, at the U.S. Geological Survey Toxic-Substances Hydrology research site located on Cape Cod, Massachusetts, was selected because it was known that the screen penetrated both the oxic and anoxic zones of the sewage plume from the Otis Air Base sewage-disposal sand beds. Well-purging experiments were conducted in 1992 and 1994. Well F453-63 was sampled over time as it was pumped continuously, and multilevel samplers were used to document the vertical distribution of selected chemicals in the ground water in the immediate vicinity of the well. The data collected from the 1992 experiment were documented previously in Reilly (1994). This report documents the data collected from the 1994 experiment.

INTRODUCTION

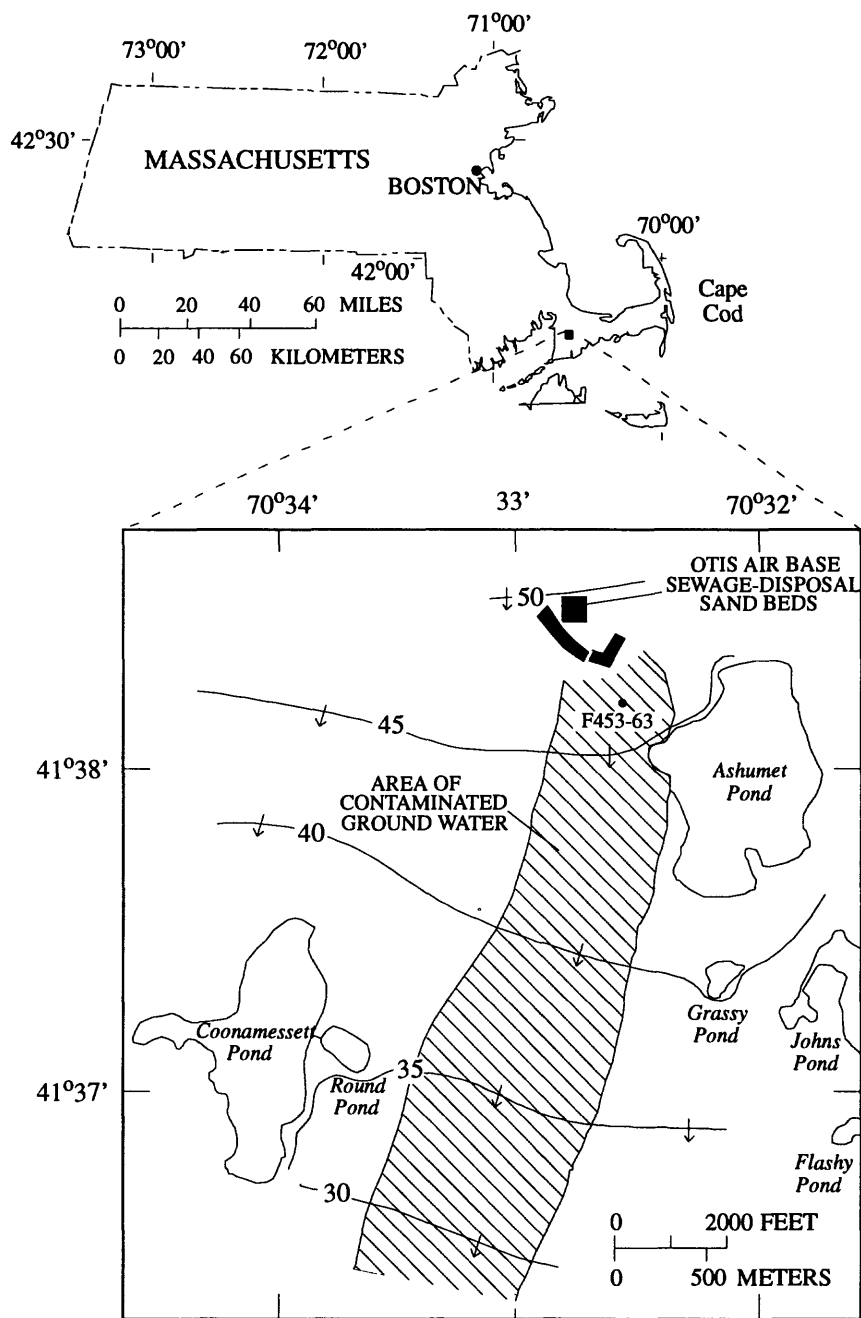
Water that enters a well through a well screen is derived from layers of porous material. These layers have different thicknesses and areal extents and can be characterized by different physical properties, such as hydraulic conductivity, and chemical properties. Layers defined by one physical or chemical property may not coincide with those defined by a different property. The water withdrawn from the well is a composite of the waters present in these different layers along the length of the screen. The length of well screens can span vertical distances shorter than 1 foot or longer than a hundred feet. The rate of water withdrawn from each layer is variable and depends on the hydraulic conductivity, screen placement, pump-intake placement, and other factors.

Wilson and Rouse (1983), Rivett and others (1990), Gibs and Imbrigiotta (1990), Reilly and Gibs (1993), and others have observed that chemical concentrations of various constituents can change in the water that discharges from a well over the time of sampling. Reilly and Gibs (1993) numerically simulated a hypothetical system to illustrate that the chemical composition of water discharging over time from a physically and chemically heterogeneous aquifer can change depending on the distribution of the chemical constituents of the water and the hydraulic conductivity of the aquifer. This simulation showed that changes over time are not necessarily caused by the evacuation of the stagnant water in the well casing but can also be caused by the transport of the chemical constituents through the aquifer to the well.

The purpose of this report is to present the data collected from an experiment performed in 1994 at Cape Cod, Massachusetts, to test the hypotheses that (1) the observed concentration of constituents in the water sampled from a screened well is due to the flux of these constituents into the well as determined by the hydraulic conductivity and chemical distribution near the well, and (2) the flux of these constituents can change during pumping as a result of the flow and transport of the chemicals in the aquifer near the screen. An earlier experiment was conducted in 1992, and those data are reported in a report by Reilly (1994).

EXPERIMENTAL DESIGN

The experiments were designed to evaluate the changing chemical composition of the water discharged from a well screened in a physically and chemically heterogeneous aquifer. Well F453-63, at the U.S. Geological Survey Toxic-Substances Hydrology research site located on Cape Cod, Massachusetts, was selected because it was known that the screen penetrated both the oxic and anoxic zones of the sewage plume from the Otis Air Base sewage-disposal sand beds (fig. 1). The groundwater chemistry differs in the oxic and anoxic zones (Kent and others, 1994), thereby providing a heterogeneous chemical environment along the screened interval of well F453-63. The horizontal hydraulic conductivity along well F453-63 is also heterogeneous and ranges from 78 to 969 ft/d (Hess, 1994). These values of hydraulic conductivity were estimated by means of a field hydraulic test that is a modification of a standard aquifer test where by a well is pumped and the drawdown is observed in the well. A highly sensitive, impeller flowmeter is used to measure the discharge within the well at various points along the screened interval instead of measuring only the total discharge flowing from the pumped well as is done in a standard aquifer test. The gain in discharge between two flowmeter measurement points is related to the hydraulic conductivity of the aquifer over that interval. Rehfeldt and others (1989) presented the details of this method.



EXPLANATION

- 30 — WATER-TABLE CONTOUR -- Shows altitude of water table above sea level, in feet.
Arrows show direction of ground-water flow.
- F453-63. SCREENED WELL USED FOR PURGING EXPERIMENT

Figure 1. Ground-water study site on Cape Cod, Massachusetts, showing the location of the contaminant plume and the screened well used in the well-purging experiment.

Three multilevel samplers (F453M1, 2, and 3) were installed near well F453-63 in 1992, and one additional multilevel sampler (F453M4) was installed in 1994, to describe the chemical distribution in the immediate vicinity of the screened well (fig. 2). Well F453-63 is constructed of 2.067-inch inside-diameter (ID) flush-jointed threaded polyvinyl chloride (PVC) pipe with four sections of 9-ft-long 0.010-inch-slotted PVC screens (Appendix 1). The screen extends from an altitude of 4.7 to 43.7 ft above sea level. The well was installed by a drive-and-wash technique to minimize disturbance of the aquifer around the well (Morin and others, 1988).

The multilevel samplers were installed near well F453-63 (fig. 2). The samplers were installed by a drive-and-wash technique described by LeBlanc and others (1991). Each multilevel sampler consists of 15 color-coded polyethylene tubes (0.25-inch outside diameter). The tubes run from land surface down the inside of a 1.25-inch inside-diameter (ID) PVC casing and out holes spaced every 3.3 ft drilled through the PVC. The open, down-hole end of each tube is screened with a fine nylon fabric secured with stainless-steel wire.

EXPERIMENTAL METHODS

The experiment of 1994 was a repeat of the 1992 experiment, but the sequence of sampling the multilevel samplers was changed to avoid any potential effect of mixing the water within the well-bore. The experiment was conducted on September 20 and 21, 1994. Well F453-63 was sampled over time as it was pumped continuously. The water level in well F453-63 was 45.92 ft above sea level at the time of the test (indicating a casing volume of 0.960 ft³).

The long-screened well F453-63 was pumped for 6 hours. A variable-rate submersible Keck¹ pump was set 0.6 ft below the static water level in well F453-63. The continuous discharge from the screened well was measured 29 times during the 6-hour experiment by means of a graduated cylinder; discharge ranged from 0.029 to 0.045 ft³/min and averaged 0.039 ft³/min, indicating that a volume equivalent to one casing volume was pumped about every 25 minutes. The first sample was collected 5 minutes after discharge began. Samples were then collected every 10 minutes for the first 2 hours, and every 15 minutes for the remaining 4 hours. Water samples were collected from multilevel sampler F453M2 the day after the test to document the concentrations in the immediate vicinity of the well screen. Water samples were collected from the multilevel samplers by pumping each port separately with a peristaltic pump fitted with Norprene tubing that could be connected directly to the sampler tubes. About 400 mL, about twice the volume of water standing in the tube of the deepest port, was pumped first to purge the port tubing.

¹The use of brand names in this report is for identification purposes only and does not constitute endorsement by the U.S. Geological Survey.

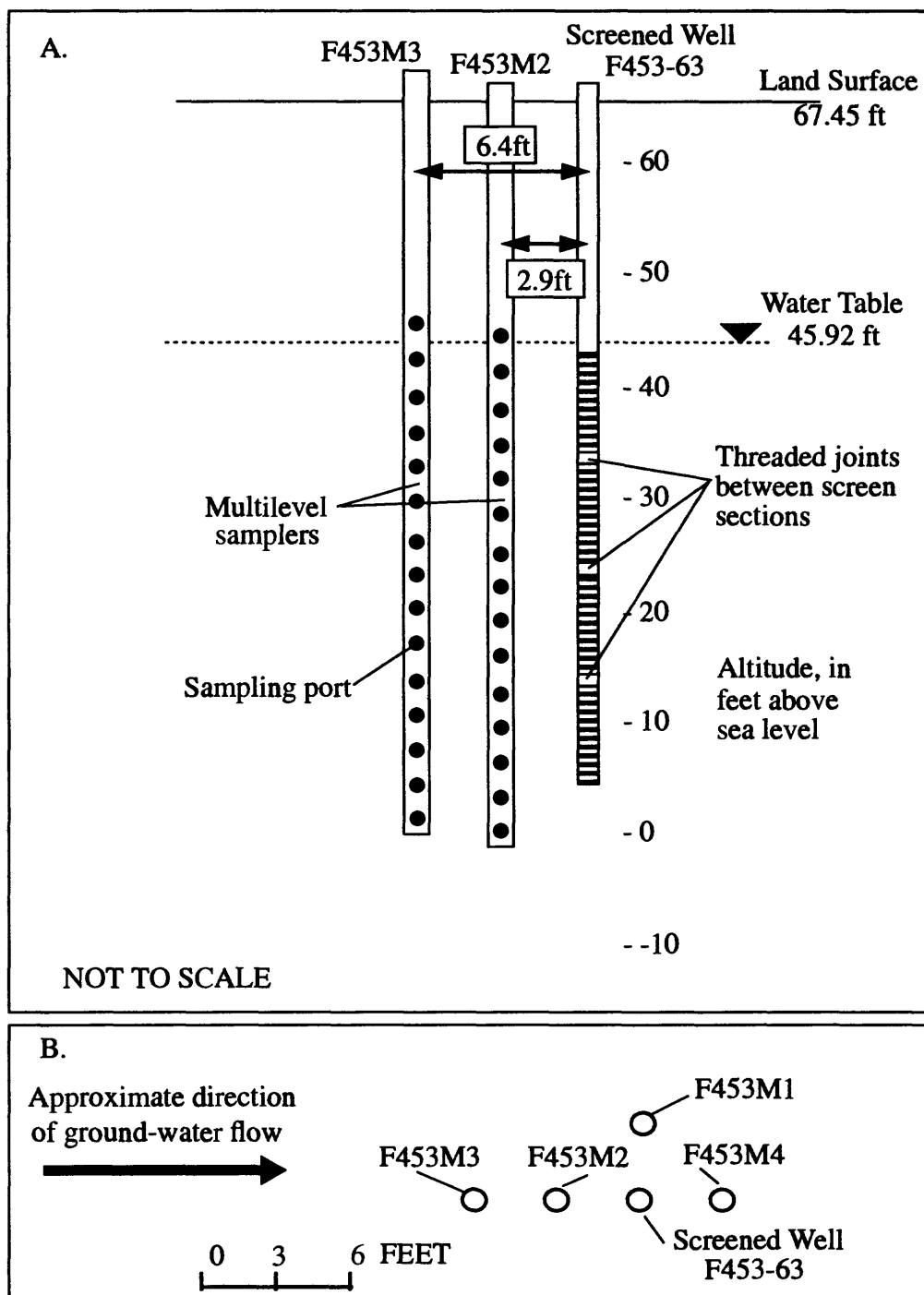


Figure 2. Diagram of well and multilevel sampler layout for well-purging experiment: A. cross-sectional view, B. Plan view.

This was a different sequence of events from the 1992 experiment. In the 1992 experiment, the multilevel samplers were sampled immediately before the screened well was pumped, and it is possible that this sampling disturbed the ambient concentrations in and around the well. The current (1994) experimental design was changed from the 1992 experiment to eliminate this potential bias. All water samples were analyzed in the field for specific conductance and pH. The samples were subsequently analyzed for concentrations of total iron, calcium, potassium, magnesium, manganese, silicon, sodium, strontium, nitrogen species (ammonium, nitrite and nitrate) and the isotopes nitrogen-15, oxygen-18, and deuterium.

CHEMICAL ANALYSES OF WATER SAMPLES

Water samples were collected during the 6-hour test from the pumped well in a 1-L polyethylene bottle that had been rinsed twice with the pumped water prior to collection of the sample. Part of the sample was decanted immediately onsite for analysis of pH and specific conductance. The remainder of the sample was filtered (using a 0.45 μm Metricell plate filter) and split immediately into other bottles for separate analysis of specific constituents. A new filter was used for each sample and was flushed with 100 mL of sample before filling bottles.

Water samples were collected from the multilevel sampler ports into a 1-L polyethylene bottle. The purge water was used to rinse the bottle prior to collection of the sample. The bottle was then filled to the top, and part of the sample was decanted immediately on site for analyses of pH and specific conductance. The remainder of the sample was split into other bottles for specific analyses as described for the pumped-well samples.

Measurement of Specific Conductance and pH

The pH and specific conductance were measured on site as the samples were taken. The specific conductance was measured with a HACH model 44600 conductivity meter. The probe was rinsed with the sample and inserted directly into the bottle to make the measurement. The specific conductance measurements for the pumped well and multilevel sampler F453M2 are given in Appendices 2 and 3, respectively.

The pH was measured with a Beckman model Φ 11 meter and an Orion 81-72B pH probe. The pH probe was inserted directly into the sample bottle, and the pH reading was recorded after it stabilized (usually within 3 to 4 minutes). The pH meter was calibrated with standard solutions with a pH of 4.0 and 7.0. The pH measurements for the pumped well and for multilevel sampler F453M2 are given in Appendices 2 and 3, respectively.

Chemical Analysis of Selected Cations

The water samples for cation determinations were collected in 60 mL acid washed bottles and preserved with nitric acid. This entailed rinsing the bottles with sample from the 1-L bottle, rinsing the filter with the sample, filtering the sample (0.45 μm filter) into the bottle, and then adding 150 μL concentrated nitric acid (HNO_3) to the sample.

The analyses were done using a Direct Current Plasma Atomic Emission Spectrophotometer [DCP-AES](ARL Spectraspan V) with an interface design ADam data acquisition package. All analytes were run undiluted with the exception of sodium which was run at a 1:10 dilution to bring the concentration within the linear dynamic range for the wavelength at which it was measured. All dilutions were made volumetrically with 0.5 percent nitric acid. The samples were analyzed for calcium, iron, manganese, magnesium, potassium, silica, sodium, and strontium. Standards and blanks were run every 5th sample to correct for instrument drift. The selected cation concentrations in the water from the pumped well and for multilevel sampler F453M2 are given in Appendices 4 and 5, respectively. A random sample was analyzed 5 times throughout the run and the deviation in the results reported as the standard error in measurements. The standard errors for each cation are: calcium (± 0.1 mg/L), iron (± 0.01 mg/L), manganese (± 0.005 mg/L), magnesium (± 0.05 mg/L), potassium (± 0.1 mg/L), silica (± 0.05 mg/L), sodium (± 1 mg/L), and strontium (± 0.005 mg/L).

Chemical Analysis of Ammonium, Nitrate, and Nitrite

Ammonium, nitrate, and nitrite determinations were performed on all water samples. Water samples for ammonium, nitrate and nitrite analyses were filtered (0.45 μm filter) from the 1-L bottle, and the filtrate was collected in 60-mL bottles. The water sample for nitrate and nitrite analysis was preserved by freezing. The water samples for ammonium was preserved with 200 μL of concentrated sulfuric acid (H_2SO_4)

Nitrate, nitrite, and ammonium concentrations were measured by using automated colorimetric methods. Nitrate concentrations were measured by cadmium reduction followed by diazotization with sulfanilamide and coupling with N-(1-naphthyl) ethylenediamine; nitrite concentrations were measured by the same technique without the cadmium reduction. Ammonium concentrations were measured by reaction with hypochlorous acid and salicylate in the presence of nitroferricyanide. Detection limits, precision, and accuracy for all three analytical techniques were estimated by Antweiler and others (in press). The ammonium, nitrate and nitrite concentrations in the water from the pumped well and for multilevel sampler F453M2 are given in Appendices 6 and 7, respectively.

STABLE ISOTOPE ANALYSES OF WATER AND NITRATE

Stable isotope ratios may offer useful alternatives to chemical concentrations in the evaluation of the source of water from wells with long screens. To test that hypothesis, stable isotope analyses were performed on hydrogen in water, oxygen in water, and nitrogen in nitrate in all samples from the multilevel sampler plus representative samples from the long-screen well. The stable isotope ratios are reported relative to a standard as δ (delta) values in units of parts per thousand, as defined for each element by:

$$\delta_x = \left[\frac{R_x}{R_s} - 1 \right] \times 1,000$$

where R_x and R_s are ratios $^2\text{H}/^1\text{H}$, $^{15}\text{N}/^{14}\text{N}$, and $^{18}\text{O}/^{16}\text{O}$ of the sample and standard, respectively. Oxygen and hydrogen isotope values for water are reported relative to the Vienna Standard Mean Ocean Water (VSMOW) reference. The nitrogen isotope values are reported relative to atmospheric N_2 . The values of $\delta^2\text{H}[\text{H}_2\text{O}]$, $\delta^{18}\text{O}[\text{H}_2\text{O}]$, and $\delta^{15}\text{N}[\text{NO}_3^-]$ in samples from the pumped well and for multilevel sampler F453M2 are given in Appendices 8 and 9, respectively.

Samples for isotope analysis were filtered and collected in 250 mL polyethylene bottles that were chilled immediately and frozen by the evening of collection. Isotope analyses were performed in the U.S. Geological Survey, Water Resources Division (WRD), Reston Stable Isotope Laboratory, approximately 1 year after the test. Subsamples for the analyses were taken within a few hours after the frozen samples were thawed completely in the laboratory at room temperature.

For hydrogen isotope measurement, a 2 mL split from each sample was equilibrated with H_2 gas at 30°C and 1 atm for 1 hour. The H_2 gas was then admitted to a dedicated mass spectrometer for analysis against a H_2 reference gas. For oxygen isotope measurement, a 2 mL split from each sample was equilibrated with CO_2 gas at 25°C and 0.5 atm for 7 hours. The CO_2 was then admitted to a dedicated mass spectrometer for analysis against a CO_2 reference gas. The hydrogen and oxygen isotope analyses were done in duplicate, and calibrated by interspersed analyses of laboratory standard waters whose values are known with respect to the normalized scale defined by VSMOW and SLAP (Coplen, 1988).

The nitrogen isotope analyses were performed on N_2 gas produced by combustion from nitrate (plus minor amounts of nitrite and organic N, if present). A split from each sample containing approximately 10-20 μmole of nitrate was titrated with KOH to a pH value of 9 to 10, freeze-dried in a polyethylene Erlenmeyer flask, redissolved in 1 mL of de-ionized water, then freeze-dried again in

a quartz tube open at one end. Combustion reagents (0.2 g of CaO plus 2.0 g of a Cu-Cu₂O mixture) were added to the tube, which was then sealed under a vacuum and baked (held at 850°C for 2 hours, then cooled at 40°C/hr to room temperature). N₂ gas was admitted to the mass spectrometer by breaking the tube under vacuum at the inlet with no further purification. The nitrogen isotope analyses were calibrated by interspersed analyses of laboratory standard nitrate salts and solutions whose values are known with respect to the normalized scale provisionally defined by IAEA-N1 (+0.4) and USGS-32 (+180) (Böhlke and Coplen, 1995).

SUMMARY

An experiment was conducted on September 20 and 21, 1994, to examine the concentration of various chemical constituents during purging of a 2-inch well with a 39-ft-long screened interval. The purpose of the experiment was to examine the hypothesis that the distributions of hydraulic conductivity and chemical concentrations near a well affect the concentrations in water pumped from the well as it is purged. The data collected and the results of the chemical analysis of the water samples are presented in this data summary report.

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APPENDICES

Appendix 1. Construction information for well F453-63

Land-surface altitude, in feet above sea level: 67.45 ft

MP (Measuring Point) height: 1.50 ft

MP altitude: 68.95 ft

Well has four lengths of 0.010-inch-slotted screen that are nominal 2-inch ID PVC pipe with flush-jointed threaded connections.

Screen Section No.	Depth below land surface, in ft		Depth below MP, in ft		Altitude, in ft	
	Top	Bottom	Top	Bottom	Top	Bottom
1	23.78	32.78	25.28	34.28	43.67	34.67
2	33.82	42.79	35.32	44.29	33.63	24.66
3	43.83	52.80	45.33	54.30	23.62	14.65
4	53.78	62.75	55.28	64.25	13.67	4.70

Appendix 2. Change in pH and specific conductance over time in water from well F453-63,
September 20,1994

Time (min)	pH	Specific Conductance (μ S/cm)
5	5.92	393
10	5.88	384
20	5.91	380
30	5.95	380
40	5.97	377
50	5.95	376
60	5.95	373
70	5.94	378
80	5.93	377
90	5.95	375
100	5.95	374
110	5.95	374
120	5.95	374
135	5.94	375
150	5.93	373
165	5.93	374
180	5.94	373
195	5.96	373
210	5.95	373
225	5.92	372
240	5.91	374
255	5.93	373
270	5.95	372
285	5.92	372
300	5.91	371
315	5.92	373
330	5.93	371
345	5.93	371
360	5.93	372

Appendix 3. Specific conductance and pH in water from each port of multilevel sampler F453-M2, Sept. 21, 1994.

ID	Altitude of Sampling Port (ft)	pH	Specific Conductance (μ S/cm)
F453-M2-PT	45.08	5.39	63.0
F453-M2-GT	43.08	5.60	58.5
F453-M2-RT	39.78	5.86	299.
F453-M2-BUT	36.50	5.93	443.
F453-M2-BKT	33.20	6.00	462.
F453-M2-WT	29.90	6.03	462.
F453-M2-O	26.59	6.10	462.
F453-M2-GY	23.29	6.13	444.
F453-M2-Y	19.99	6.13	436.
F453-M2-P	16.50	6.15	462.
F453-M2-GN	13.20	5.25	385.
F453-M2-R	9.90	5.43	431.
F453-M2-BU	6.60	5.76	430
F453-M2-BK	3.30	6.01	322.
F453-M2-W	0.00	6.62	397.

Appendix 4. Cation concentrations, in milligrams per liter, over time in water from well F453-63

Time (min)	Calcium	Magnesium	Sodium	Potassium	Strontium	Silicon	Iron	Manganese
5	12.3	3.50	48	16.7	0.095	6.25	0.88	0.28
10	13.0	3.70	48	16.4	0.105	6.35	0.73	0.30
20	13.9	4.00	46	14.7	0.110	6.25	0.57	0.30
30	14.8	4.20	46	13.8	0.120	6.30	0.42	0.32
40	15.7	4.50	44	13.5	0.125	6.35	0.37	0.32
50	15.2	4.40	42	13.5	0.120	6.30	0.40	0.32
60	15.1	4.45	43	13.6	0.120	6.25	0.39	0.32
70	15.6	4.45	43	13.3	0.125	6.40	0.40	0.33
80	15.7	4.65	44	13.3	0.130	6.45	0.38	0.34
90	15.0	4.35	45	13.2	0.125	6.25	0.37	0.32
100	15.0	4.40	43	12.7	0.120	6.20	0.37	0.32
110	15.3	4.45	43	12.7	0.125	6.25	0.32	0.32
120	15.3	4.55	42	13.0	0.130	6.35	0.38	0.33
135	15.5	4.55	42	12.4	0.125	6.30	0.35	0.33
150	15.7	4.60	43	12.5	0.130	6.50	0.33	0.34
165	15.1	4.55	43	13.0	0.125	6.40	0.39	0.34
180	15.5	4.55	42	12.6	0.130	6.45	0.34	0.33
195	15.6	4.55	41	12.4	0.130	6.40	0.33	0.34
210	15.5	4.60	42	12.8	0.130	6.25	0.36	0.34
225	15.5	4.65	42	12.4	0.130	6.30	0.31	0.34
240	15.5	4.70	41	12.5	0.130	6.35	0.32	0.34
255	15.7	4.70	41	12.6	0.135	6.40	0.35	0.34
270	15.6	4.60	40	12.5	0.130	6.45	0.35	0.34
285	15.0	4.50	40	12.3	0.125	6.30	0.36	0.33
300	14.9	4.45	41	12.7	0.130	6.60	0.39	0.33
315	15.4	4.70	42	12.7	0.135	6.45	0.34	0.34
330	15.2	4.50	40	12.3	0.130	6.35	0.33	0.33
345	15.4	4.55	41	12.2	0.130	6.35	0.33	0.33
360	15.8	4.75	41	12.4	0.135	6.55	0.33	0.35

Appendix 5. Cation concentrations, in milligrams per liter, in water from each port of multilevel sampler F453-M2, Sept. 21, 1994.

ID	Altitude of Sampling Port (ft)	Calcium	Magnesium	Sodium	Potassium	Strontium	Silicon	Iron	Manganese
F453-M2-PT	45.08	0.85	1.3	7.0	0.7	0.010	2.7	0.01	0.005
F453-M2-GT	43.08	1.2	0.92	6.4	1.1	0.010	3.9	0.01	0.015
F453-M2-RT	39.78	14.	3.8	32.	8.0	0.16	6.3	0.07	0.24
F453-M2-BUT	36.50	24.	6.6	46.	11.5	0.23	6.7	0.06	0.65
F453-M2-BKT	33.20	27.	5.6	48.	13.	0.20	7.3	0.06	0.54
F453-M2-WT	29.90	25.	6.0	53.	14.	0.27	7.6	0.07	0.56
F453-M2-O	26.59	21.	8.5	53.	13.	0.20	7.4	0.06	0.51
F453-M2-GY	23.29	25.	5.3	49.	13.	0.18	7.0	0.05	0.44
F453-M2-Y	19.99	22.	5.0	51.	13.	0.14	7.0	0.05	0.34
F453-M2-P	16.50	20.	8.1	51.	19.	0.20	7.1	0.05	0.48
F453-M2-GN	13.20	5.9	1.3	51.	17.	0.045	6.9	2.0	0.36
F453-M2-R	9.90	3.1	0.85	54.	37.	0.030	5.9	0.25	0.16
F453-M2-BU	6.60	6.0	2.35	52.	25.	0.060	5.5	4.8	0.30
F453-M2-BK	3.30	2.5	0.95	43.	5.0	0.020	6.4	6.3	0.11
F453-M2-W	0.00	9.7	3.5	49.	7.0	0.050	5.9	20.	0.42

Appendix 6. Ammonium, nitrate and nitrite concentrations, in milligrams per liter as nitrogen (mg/L - N), over time in water from well F453-63, Sept. 21, 1994

Time (min)	nitrite - NO ₂	nitrate - NO ₃	ammonium - NH ₄
5	0.24	12.23	0.32
10	0.23	12.17	0.27
20	0.19	11.84	0.23
30	0.16	12.01	0.22
40	0.15	11.99	0.17
50	0.16	11.88	0.18
60	0.16	11.87	0.20
70	0.15	12.20	0.18
80	0.15	12.17	0.19
90	0.15	12.13	0.20
100	0.16	12.02	0.19
110	0.14	11.87	0.18
120	0.15	12.21	0.18
135	0.15	12.05	0.16
150	0.15	11.98	0.19
165	0.16	12.07	0.19
180	0.15	11.93	0.19
195	0.14	11.99	0.18
210	0.15	11.81	0.16
225	0.14	12.02	0.16
240	0.15	11.89	0.16
255	0.15	12.01	0.13
270	0.14	11.86	0.16
285	0.13	10.39	0.19
300	0.17	10.28	0.17
315	0.15	12.3	0.18
330	0.14	11.86	0.18
345	0.15	11.91	0.12
360	0.13	10.73	0.14

Appendix 7. Ammonium, nitrate and nitrite concentrations, in milligrams per liter as nitrogen (mg/L - N), in water from each port of multilevel sampler F453-M2, Sept. 21, 1994.

ID	Altitude of Sampling Port (ft)	nitrite - NO ₂	nitrate - NO ₃	ammonium - NH ₄
F453-M2-PT	45.08	0.0	0.01	0.07
F453-M2-GT	43.08	0.0	0.48	0.07
F453-M2-RT	39.78	0.0	9.86	0.07
F453-M2-BUT	36.50	0.01	16.08	0.19
F453-M2-BKT	33.20	0.04	17.22	0.12
F453-M2-WT	29.90	0.06	16.4	0.12
F453-M2-O	26.59	0.20	16.03	0.10
F453-M2-GY	23.29	0.07	12.73	0.10
F453-M2-Y	19.99	0.11	11.25	0.12
F453-M2-P	16.50	0.44	14.49	0.12
F453-M2-GN	13.20	0.35	12.05	1.81
F453-M2-R	9.90	0.02	15.45	0.12
F453-M2-BU	6.60	0.37	14.75	0.53
F453-M2-BK	3.30	0.01	1.75	0.24
F453-M2-W	0.00	0.0	0.01	1.21

Appendix 8. The values of $\delta^2\text{H}$, $\delta^{18}\text{O}$, $\delta^{15}\text{N}$ in water and nitrate from selected times in water from well F453-63, Sept. 21, 1994.

Time (min)	$\delta^{15}\text{N}$ in NO_3^-	$\delta^{18}\text{O}$ in H_2O	$\delta^2\text{H}$ in H_2O
10	23.5	-6.84	-42.6
20	22.7	-6.82	-41.5
110	21.3	-6.88	-43.4
120	21.2	-6.86	-42.1
210	21.0	-6.86	-43.3
225	21.0	-6.86	-42.0
285	21.2	-6.91	-42.2
300	21.1	-6.84	-43.4
315	21.2	-6.87	-42.1

Appendix 9. The values of $\delta^2\text{H}$, $\delta^{18}\text{O}$, $\delta^{15}\text{N}$ in water and nitrate from each port of multilevel sampler F453-M2, Sept. 21, 1994.

ID	Altitude of Sampling Port (ft)	$\delta^{15}\text{N}$ in NO_3^-	$\delta^{18}\text{O}$ in H_2O	$\delta^2\text{H}$ in H_2O
F453-M2-PT	45.08	--	-8.97	-56.7
F453-M2-GT	43.08	11.5	-8.76	-54.5
F453-M2-RT	39.78	14.9	-6.91	-40.8
F453-M2-BUT	36.50	16.9	-6.70	-40.8
F453-M2-BKT	33.20	18.6	-6.66	-40.9
F453-M2-WT	29.90	21.5	-6.66	-40.7
F453-M2-O	26.59	21.3	-6.69	-40.5
F453-M2-GY	23.29	23.1	-6.65	-42.7
F453-M2-Y	19.99	24.9	-6.70	-40.6
F453-M2-P	16.50	23.7	-6.62	-41.0
F453-M2-GN	13.20	27.1	-6.64	-41.7
F453-M2-R	9.90	25.6	-6.81	-41.3
F453-M2-BU	6.60	26.6	-6.82	-41.9
F453-M2-BK	3.30	43.2	-6.89	-41.9
F453-M2-W	0.00	--	-6.95	-41.9