Prepared in cooperation with the City of Houston

Groundwater Quality of the Gulf Coast Aquifer System, Houston, Texas, 2007–08

Data Series 548
Revised July 2011

U.S. Department of the Interior
U.S. Geological Survey

Front cover:

Top, U.S. Geological Survey hydrologist collecting a groundwater sample inside a collection chamber while standing inside the dedicated mobile water-quality laboratory truck.

Middle, Dedicated mobile water-quality laboratory truck with sample collection line feeding through portal and attached to spigot near wellhead.

Bottom, U.S. Geological Survey hydrologist writing field measurements of selected physicochemical properties while inside the dedicated mobile water-quality laboratory truck.

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KEN SALAZAR, Secretary

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Radioactivity	
picocurie per liter (pCi/L)	0.037	becquerel per liter (Bq/L)

SI to Inch/Pound

Multiply	By	To obtain
	Length	
nanometer (nm)	3.937×10^{-8}	inch (in.)
micrometer (µm)	3.937×10^{-5}	inch (in.)
millimeter (mm)	0.03937	inch (in.)
kilometer (km)	0.6214	mile (mi)
	Volume	
microliter (µL)	3.382×10^{-5}	ounce, fluid (fl. oz)
milliliter (mL)	0.03382	ounce, fluid (fl. oz)
liter (L)	33.82	ounce, fluid (fl. oz)
	Mass	
gram (g)	0.03527	ounce, avoirdupois (oz)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

$$°F=(1.8\times°C)+32$$

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm).

Concentrations of chemical constituents in water are given in either milligrams per liter (mg/L) or micrograms per liter (µg/L).

Groundwater Quality of the Gulf Coast Aquifer System, Houston, Texas, 2007–08

By Jeannette H. Oden, Timothy D. Oden, and Zoltan Szabo

Abstract

In the summers of 2007 and 2008, the U.S. Geological Survey (USGS), in cooperation with the City of Houston, Texas, completed an initial reconnaissance-level survey of naturally occurring contaminants (arsenic, other selected trace elements, and radionuclides) in water from municipal supply wells in the Houston area. The purpose of this reconnaissance-level survey was to characterize source-water quality prior to drinking water treatment. Water-quality samples were collected from 28 municipal supply wells in the Houston area completed in the Evangeline aquifer, Chicot aquifer, or both. This initial survey is part of ongoing research to determine concentrations, spatial extent, and associated geochemical conditions that might be conducive for mobility and transport of these constituents in the Gulf Coast aquifer system in the Houston area.

Samples were analyzed for major ions (calcium, magnesium, potassium, sodium, bromide, chloride, fluoride, silica, and sulfate), selected chemically related properties (residue on evaporation [dissolved solids] and chemical oxygen demand), dissolved organic carbon, arsenic species (arsenate [As(V)], arsenite [As(III)], dimethylarsinate [DMA], and monomethylarsonate [MMA]), other trace elements (aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, selenium, silver, strontium, thallium, vanadium, and zinc), and selected radionuclides (gross alpha- and beta-particle activity [at 72 hours and 30 days], carbon-14, radium isotopes [radium-226 and radium-228], radon-222, tritium, and uranium). Field measurements were made of selected physicochemical (relating to both physical and chemical) properties (oxidation-reduction potential, turbidity, dissolved oxygen concentration, pH, specific conductance, water temperature, and alkalinity) and unfiltered sulfides. Dissolved organic carbon and chemical oxygen demand are presented but not discussed in the report.

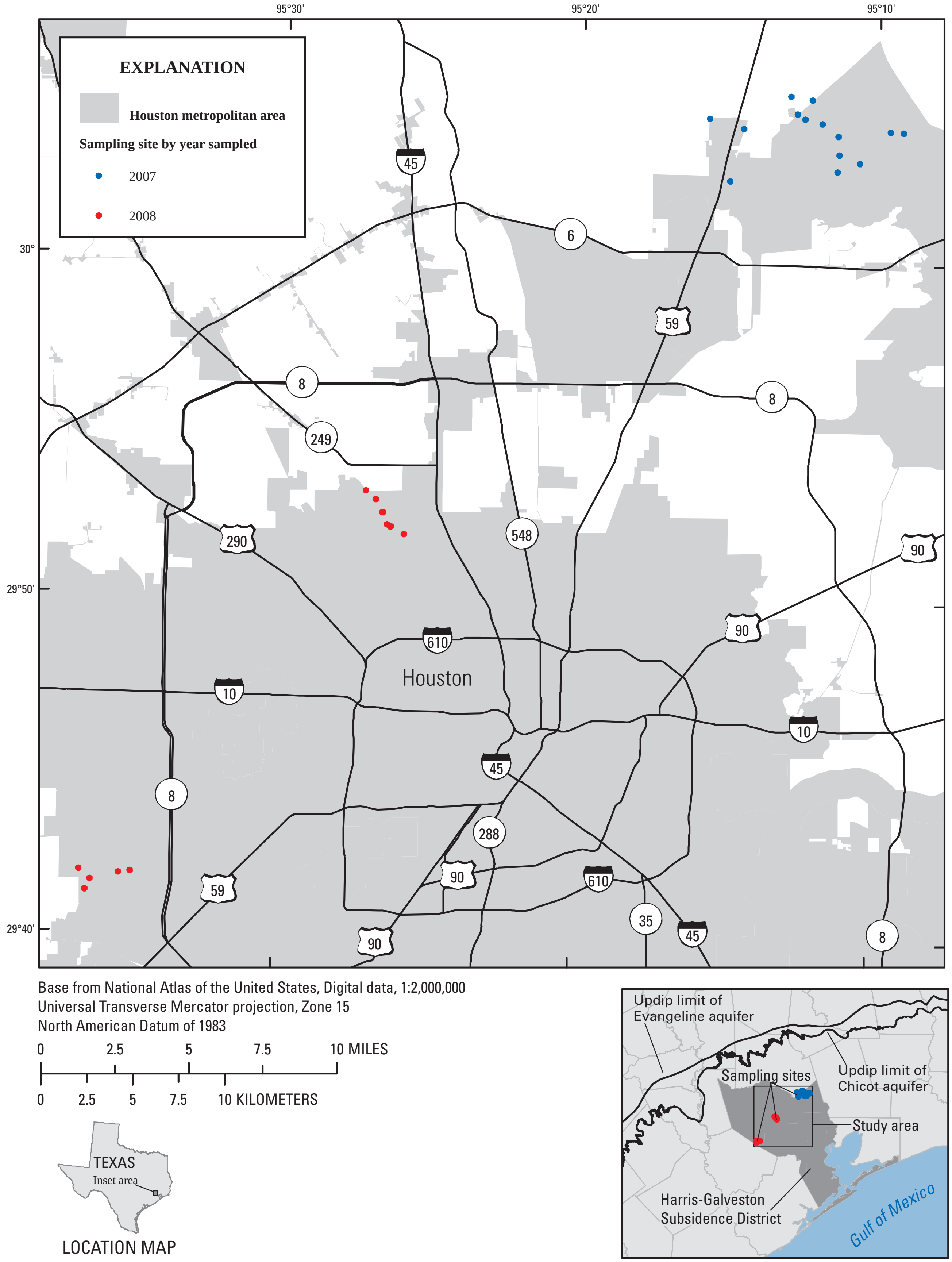
Physicochemical properties, major ions, and trace elements varied considerably. The pH ranged from 7.2 to 8.1 (median 7.6); specific conductance ranged from 314 to 856 microsiemens per centimeter at 25 degrees Celsius, with a median of 517 microsiemens per centimeter; and alkalinity ranged from 126 to 324 milligrams per liter as calcium carbonate (median 167 milligrams per liter). The range in oxidation-reduction potential was large, from -212 to 244 millivolts, with a median of -84.6 millivolts. The largest ranges in concentration for filtered major ion constituents were obtained for cations sodium and calcium and for anions chloride and bicarbonate (bicarbonate was calculated from the measured alkalinity). Filtered arsenic was detected in all 28 samples, ranging from 0.58 to 15.3 micrograms per liter (median 2.5 micrograms per liter), and exceeded the maximum contaminant level established by the U.S. Environmental Protection Agency of 10 micrograms per liter in 2 of the 28 samples. As(III) was the most frequently detected arsenic specie. As(III) concentrations ranged from less than 0.6 to 14.9 micrograms arsenic per liter. The range in concentrations for the arsenic species As(V) was from less than 0.8 to 3.3 micrograms arsenic per liter.

Barium, boron, lithium, and strontium were detected in quantifiable (equal to or greater than the laboratory reporting level) concentrations in all samples and molybdenum in all but one sample. Filtered iron, manganese, nickel, and vanadium were each detected in at least 18 of the 28 samples. All other selected trace elements were each detected in 16 or fewer samples.

Radionuclides were detected in most samples. The gross alpha-particle activities at 30 days and 72 hours ranged from R-0.94 to 15.5 and R-1.1 to 17.2 picocuries per liter, respectively ("R" indicates nondetected result less than the sample-specific critical level). The combined radium (radium-226 plus radium-228) concentrations ranged from an estimated value of 0.246 to 3.23 picocuries per liter, with a median concentration of 1.16 picocuries per liter. Radon-222 concentrations ranged from 161 to 2,230 picocuries per liter (median 550 picocuries per liter). The filtered uranium concentrations ranged from less than 0.02 to 17.4 micrograms per liter (median 0.26 microgram per liter).

Introduction

Groundwater is used for much of the municipal water supply needs of the Houston, Tex., area, and the primary sources of groundwater for the Houston area are the Evangeline and Chicot aquifers of the Gulf Coast aquifer



Base from National Atlas of the United States, Digital data, 1:2,000,000
Universal Transverse Mercator projection, Zone 15
North American Datum of 1983

Figure 1. Location of 28 municipal supply wells in the Houston, Texas, area sampled during 2007–08.

system (fig. 1). During 2008, the U.S. Geological Survey (USGS), in cooperation with the city of Houston, completed an initial reconnaissance-level survey of selected naturally occurring trace elements and radionuclides in water from selected municipal supply wells in the Houston area. Water-quality samples were collected from 28 municipal supply wells completed in the Evangeline and Chicot aquifers of the Gulf Coast aquifer system. The wells were clustered in three areas—one is northeast, the second northwest, and the third southwest of the central part of Houston, which is inside Interstate 610 (Loop 610) (fig. 1). Selected physicochemical (relating to both physical and chemical) properties and unfiltered sulfides were measured in the field in conjunction with each sample collected. Samples were analyzed for major ions, selected chemically related properties, dissolved organic carbon (DOC), arsenic species, other selected trace elements, and selected radionuclides. Results for DOC and chemical oxygen demand (COD) are presented but not discussed in this report. This initial survey is part of ongoing research to determine concentrations, spatial extent, and associated geochemical conditions that might be conducive for mobility and transport of these constituents in the Gulf Coast aquifer system in the Houston area.

Many contaminants in groundwater are naturally occurring in aquifers. In a national survey of more than 6,000 domestic wells used for drinking-water supply, naturally occurring contaminants were many times more prevalent in concentrations of concern than were synthetic organic compounds released to the environment by human activity and considered to pose health risks upon ingestion (DeSimone, 2009). The local geology and geochemistry of an aquifer control the occurrence and distribution of naturally occurring contaminants in groundwater, such as arsenic, other trace elements, and radionuclides. For example, arsenic species are soluble in a variety of geochemical conditions, and each specie of arsenic has different mobilities and health effects (Abernathy and Chappell, 1997; National Research Council, 1999; Smedley and Kinninburgh, 2002). Inorganic arsenic can occur in several forms or species, but it primarily occurs as trivalent arsenite (As[III]) or pentavalent arsenate (As[V]) in natural waters. Dimethylarsinate (DMA) and monomethylarsonate (MMA) are two organic species that can be present in natural waters (Garbarino and others, 2002).

Proposed and implemented changes to drinking water regulations have increased the number of community water systems that will need to be monitored and receive mitigation for these contaminants (U.S. Environmental Protection Agency, 2000). Water managers' knowledge about the occurrence and distribution of arsenic and radionuclides has become essential for treatment purposes. For example, recent changes to the U.S. Environmental Protection Agency (USEPA) public drinking-water regulations for arsenic and a selected number of natural radionuclides have highlighted the necessity for municipal water-supply managers to be concerned about the occurrence and distribution of these constituents in their respective drinking-water resources, primarily pertaining to groundwater. The National Research Council (1999) recommended the USEPA to lower the maximum contaminant level (MCL) for arsenic because of ongoing health research that associated the occurrence of arsenic in water to the increased risk of skin and internal cancers in humans. In 2002, the USEPA lowered the MCL for arsenic in drinking water from 50 to 10 micrograms per liter (µg/L) and required municipal supply systems to comply with the new standard by January 23, 2006 (U.S. Environmental Protection Agency, 2001).

In December 2000, the USEPA updated the regulations pertaining to radionuclides (except radon-222) in drinking water (U.S. Environmental Protection Agency, 2000). The revised MCLs are listed in table 1. The new monitoring requirements for the radionuclide contaminants defined in 2000 were phased in between December 2003 and December 31, 2007, the date for all water systems to complete initial monitoring (U.S. Environmental Protection Agency, 2000). The USEPA MCL for gross alpha-particle activity is 15 picocuries per liter (pCi/L) minus activity caused by uranium and radon, if applicable (U.S. Environmental Protection Agency, 2000). The regulation defines the maximum holding time as 6 months for samples to be analyzed for gross alpha-particle activity. For beta-particle activity, the USEPA rule states that the water systems must increase monitoring frequency if the gross beta-particle activity minus the naturally occurring potassium-40 activity is equal to or greater than 50 pCi/L, and individual isotopes may be targeted for analysis (U.S. Environmental Protection Agency, 2000). The radium MCL is defined as 5 pCi/L for the sum of the radium isotopes, radium-226 and radium-228 (the sum of which is referred to as combined Ra). The revised monitoring requirements included monitoring for radium-228 as well as radium-226, and they required water system managers to monitor for these radioactive constituents at each entry point into a distribution

Table 1. Maximum contaminant levels for arsenic and radionuclides in drinking water, January 2009.

[µg/L, micrograms per liter; pCi/L, picocuries per liter; mrem/yr, millirems per year]

Constituent	Maximum contaminant level[1]
Arsenic	10 µg/L
Gross alpha-particle activity	15 pCi/L[2]
Beta/photon emitters	4 mrem/yr (50 pCi/L screen)[3]
Radium-226 plus radium-228 (combined radium)	5 pCi/L
Uranium	30 µg/L
Radon-222 (proposed)	300 or 4,000 pCi/L

[1] Additional information regarding regulation of radionuclides in drinking water available from U.S. Enviromental Protection Agency (2010).

[2] Excluding uranium and radon.

[3] Dose (millirems per year) determined on basis of individual isotope analyses.

system. Also, the sampling frequency requirements for radionuclides were changed to be more consistent with those required for other drinking water standards. This “radioactivity rule” also established a new MCL of 30 μg/L for uranium, which previously had been unregulated (U.S. Environmental Protection Agency, 2000).

USEPA proposed separate regulation for radon-222 in drinking water in 1999, with an MCL of 300 pCi/L (U.S. Environmental Protection Agency, 1999) that has yet (2010) to be adopted. The proposed rule also defined an alternative MCL of 4,000 pCi/L for radon-222. This rule would be used to regulate community water systems with established multimedia mitigation programs to address radon-222 risks (U.S. Environmental Protection Agency, 1999). To date, these proposed MCLs for radon-222 are considered guidance levels defining a range of maximum acceptable exposure risks.

Elevated concentrations of arsenic and natural radionuclides in drinking-water resources from groundwater have been documented in several regions of the United States (Focazio and others 2000; Welch and others, 2000; Focazio and others 2001; Ryker, 2003; DeSimone, 2009). Targeted reconnaissance sampling by Focazio and others (2001) showed that Texas is one of more than a dozen states with relatively large concentrations of radium in municipal water supplies obtained from aquifers. Chowdhury and others (2006) analyzed the radionuclide data available in the Texas Water Development Board groundwater database for the Gulf Coast aquifer system, which were primarily gross alpha- and beta-particle activity results, with a few radium-226 and radon-222 analyses. The highest gross alpha-particle activities (61 to 210 pCi/L) were measured from wells screened in the Evangeline aquifer, part of the Gulf Coast aquifer system, in Harris County, Tex., and other counties south of Bee County, Tex. (Chowdhury and others, 2006; figs. 5–24). Chowdhury and others (2006) also summarized the arsenic data collected from wells screened in the Gulf Coast aquifer system in Texas and reported that arsenic concentrations ranged from 2 to 569 μg/L for samples obtained from the three aquifers (Chicot, Evangeline, and Jasper) that compose the Gulf Coast aquifer system.

Purpose and Scope

This report presents the results for physicochemical properties and water-quality constituents (major ions, DOC, arsenic species [arsenate (As[V]), arsenite (As[III]), dimethylarsinate (DMA), and monomethylarsonate (MMA)], other selected trace elements, and selected radionuclides) measured in water-quality samples from 28 municipal supply wells in the Houston area, with emphasis on the results for arsenic, other selected trace elements, and radionuclides. The purpose of this reconnaissance-level survey was to characterize source-water quality prior to drinking water treatment. The ranges of concentrations for the water-quality constituents are described, the concentrations for arsenic and radionuclides are summarized by grouping these data based on the quartiles of the dataset, and the results for arsenic and radionuclides are compared to applicable drinking-water standards established by the U.S. Environmental Protection Agency. The geographic distribution of arsenic and radionuclides measured in the 28 sampled wells is described. The methods by which the samples were collected and analyzed are described for each constituent or constituent group, and quality control results also are summarized.

Description of Study Area

Houston, Tex., is the fourth largest city in the United States and is growing; the population for the Houston metropolitan area as of January 1, 2007, was about 5.6 million, an 18.6 percent increase since the 2000 census (Texas State Data Center, 2007). Historically, the water supply for the city of Houston has been groundwater, and the groundwater withdrawals have increased over time, primarily for municipal use. Steadily increasing groundwater withdrawals in most parts of the greater Houston area for much of the city’s history resulted in declining groundwater levels, which in turn has caused land subsidence (Ryder and Ardis, 2002; Kasmarek and others, 2009). The Texas Legislature created the Harris-Galveston Subsidence District in 1975 to regulate groundwater withdrawal in the Houston area because land subsidence was increasing the risk of flooding and fault activity; an increased use of surface water to prevent future subsidence was also mandated (Ryder and Ardis, 2002). Under the 1999 regulatory plan issued by the Harris-Galveston Subsidence District, a goal was established for the northern and western parts of Harris County to reduce groundwater usage 30 percent by 2010; by 2030, the goal is for groundwater to account for less than 20 percent of total water usage in Harris and Galveston Counties (Michel, 2006). Even though the plan is to reduce the amount of groundwater used in the Houston area, the population of the area is expected to continue to grow rapidly. Maintaining the drinking-water quantity and quality of the municipal water supply is a priority for the water resource managers in the area regardless of the source.

The greater Houston area overlies and obtains all its groundwater from the Gulf Coast aquifer system. The Gulf Coast aquifer system consists mostly of unconsolidated sediments of Miocene age and younger that lie above and coastward of the Paleocene Catahoula Sandstone. The Gulf Coast aquifer system reflects three depositional environments: continental (alluvial plain), transitional (delta, lagoon, and beach), and marine (continental shelf). Coarser grained non-marine deposits updip grade laterally into finer grained material that was deposited in marine environments (Ryder, 1996). The system consists of a fluvial-deltaic wedge of discontinuous beds of sand, silt, and clay sediments deposited in bands that parallel the Gulf and range in age from Miocene to Holocene. This wedge of unconsolidated to poorly consolidated sediments increases in thickness and depth toward the Gulf (Ryder, 1996). Aquifers typically consist of interbedded sand and clay, rather than the massive, areally extensive sand beds or sheet sands common in places such as the Atlantic Coastal Plain aquifers and aquifer systems, which were deposited as beach sands or shallow-shelf sandbars in cyclic progressive/regressive sequences (Hansen, 1971; Sugarman and Miller, 1997). Lenticular sand and clay beds of the aquifer system have lateral and vertical boundaries that are gradational, poorly constrained, and difficult to trace more than a few miles (Renken, 1998). The Chicot aquifer, Evangeline aquifer, Burkeville confining unit, and Jasper aquifer comprise the Gulf Coast aquifer system (fig. 2). The Chicot and underlying Evangeline aquifers are hydraulically connected and not separated by a distinct confining unit; they are identified on the basis of a gradational decrease in grain size with depth. The Chicot and Evangeline aquifers are the primary sources of groundwater used for drinking water for the City of Houston.

Well Information

The USGS collected samples from 28 municipal supply wells during the summers of 2007 and 2008 (table 2, at end of report). Of these 28 wells, 20 were screened entirely in the Evangeline aquifer, and 1 well was screened entirely in the Chicot aquifer. The remaining seven wells contained screened intervals that intersected both aquifers. The depths of the 28 wells ranged from 565 to 1,698 feet below land surface (ft bls). Twenty-seven of the 28 wells had multiple screened intervals separated by different lengths of well casing. The depth to the top of the first screen interval for each well ranged from 321 to 1,168 ft bls, and the depth to the bottom of the last screen interval ranged from 556 to 1,689 ft bls (table 2). The lithologic code for each well summarizes the sand and clay composition of the aquifer material for the total depth of the well as reported in associated drillers' logs. A lithologic code of CLSD describes aquifer material with a greater percentage of clay than sand, as compared to a code of SDCL, which describes aquifer material with a greater percentage of sand than clay.

Methods

Sample Collection

Samples were collected and processed in accordance with protocols established by the USGS "National Field Manual for the Collection of Water-Quality Data" (U.S. Geological Survey, variously dated). These sampling protocols ensure that a representative sample of groundwater is collected at each site, and samples are collected and processed in a way that minimizes sample contamination. Groundwater samples were collected as near to the wellhead as possible, prior to treatment.

Prior to sampling, each well had been pumping for a minimum of 1 hour. Field measurements of selected physicochemical properties (oxidation reduction potential, turbidity, dissolved oxygen concentration, pH, specific conductance, and water temperature) were made; each physicochemical property was monitored for stabilization prior to sampling to ensure that the water sampled from the well was representative of water from the aquifer (U.S. Geological Survey, variously dated). Water samples were collected using Teflon tubing, C-Flex tubing, and stainless steel fittings attached to a spigot close to the wellhead and prior to any treatment. Tubing from the spigot extended into a mobile water-quality laboratory that was used for sample collection and processing. The tubing inside the mobile laboratory was connected to a Teflon manifold to split water to the sample collection chamber and to the multiparameter instrument used for measuring field parameters.

Water pumped from the well was passed through the manifold and through a flow-through chamber that contained a water-quality monitor, a YSI 600XL multiprobe water-quality sonde. The multiprobe sonde simultaneously measures oxidation-reduction potential, dissolved oxygen concentration, pH, specific conductance, and water temperature; measurements were recorded every 5 minutes.

Turbidity was measured separately in grab samples collected every 5 minutes using a Hach 2100P benchtop turbidimeter. All sensors on the multiparameter instrument and turbidimeter were calibrated daily. Field measurements were recorded at 5-minute intervals until five sequential readings of field measurements were within the stabilization criteria (Wilde and Radtke, 2005). In cases where the dissolved-oxygen concentration was less than 2.0 milligrams per liter (mg/L), the final dissolved-oxygen concentration was determined by a spectrophotometric method using the Rhodazine-D colorimetric method to minimize atmospheric interaction with the water sample (Lewis, 2006). When the dissolved oxygen was measured as less than 1.0 mg/L or the oxidation-reduction potential was less than 200 millivolts (mV), unfiltered sulfides also were measured in the field by following the Methylene Blue Method (American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 2005, Section 4500; Hach Company, 2007; CHEMetrics, 2008). In 2007, a portable Hach DR2800 spectrophotometer was used to measure the unfiltered sulfides concentrations in the field by using field supplies and an adapted method described by HACH (Hach Company, 2007). In 2008, a V–2000 photometer with CHEMetrics field supplies and method was used for this measurement (CHEMetrics, 2008). Lastly, an alkalinity was determined by the incremental titration method (U.S. Geological Survey, variously dated).

All water-quality samples, with the exception of radon-222, were collected and processed inside a field-portable collection chamber inside the dedicated mobile water-quality laboratory. A chamber consists of a frame and a new plastic-bag covering used at each site and discarded after one-time use (U.S. Geological Survey, variously dated). All samples, except those for COD, radon, and tritium analyses, were

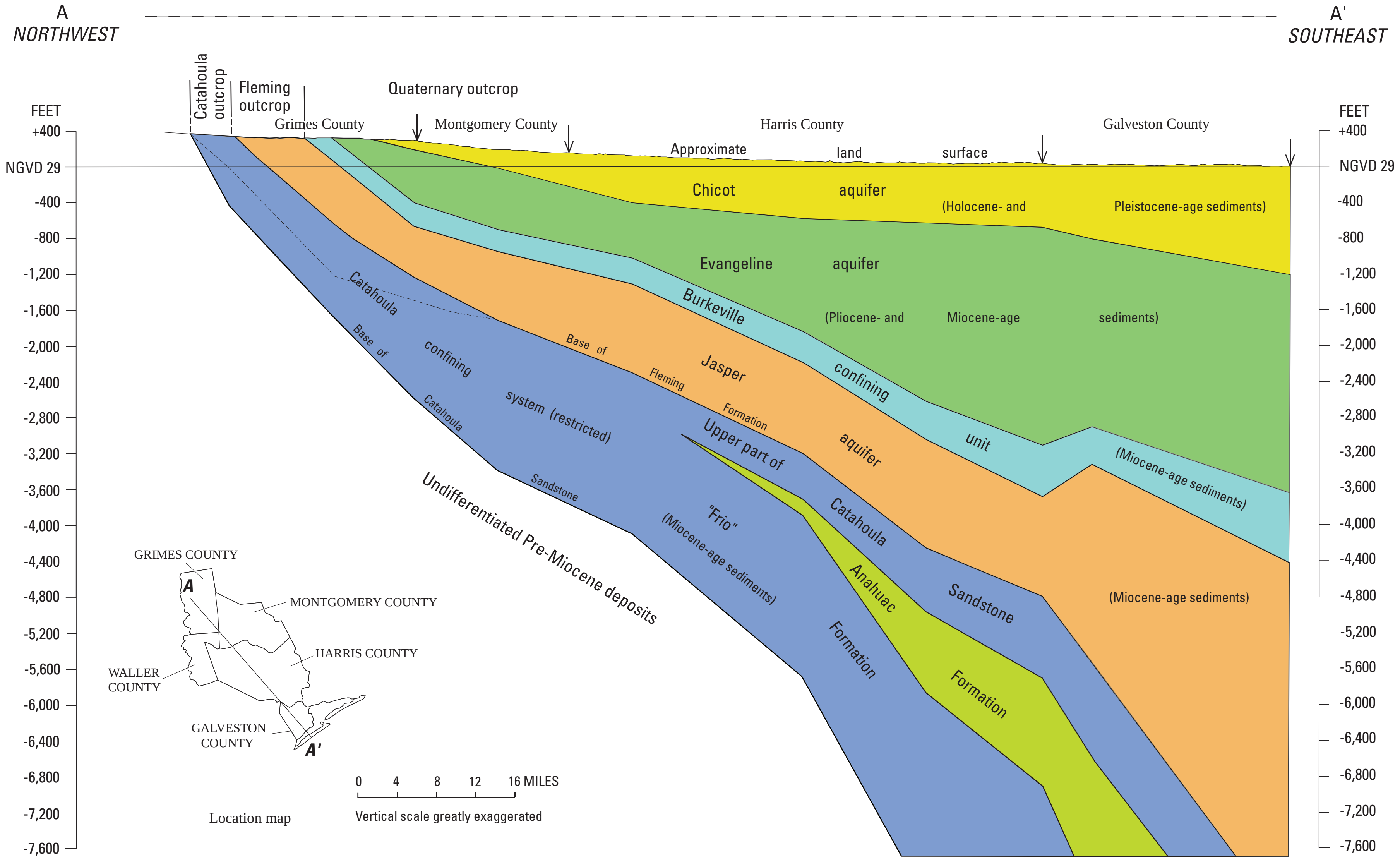


Figure 2. Hydrogeologic section of the Gulf Coast aquifer system in Harris County and adjacent counties, Texas (modified from Baker, 1979, fig. 4).

filtered during collection. Filtered samples were processed using a 0.45-micrometer polysulfone ether capsule filter. The capsule filter was preconditioned the day of use with 1 liter of ASTM (American Society for Testing and Materials) standard Type I deionized water (ASTM International, 2006a) and stored chilled until analyzed. Polyethylene bottles were preconditioned; each bottle was rinsed three times and transported to the field approximately one-half full of Type I deionized water. Upon attaching the capsule filter to the sample collection line, the air was worked out of the filter, and 100 milliliters (mL) of native water were passed through the filter before collection. The preconditioned polyethylene bottles were emptied and given a one-time 25-mL native water rinse, then filled to the shoulder of the bottle. All samples were preserved after collection, except those for major anions, carbon-14, and tritium analyses. When used, preservatives such as nitric or sulfuric acid were added to the samples in a preservation chamber. Ultrapure nitric acid was added to each bottle for cation or trace element analysis, lowering the pH to 2 or less; sulfuric acid was added to each bottle for DOC and COD analyses. The arsenic species were collected as 10 mL of filtered groundwater sample in an opaque polyethylene bottle and preserved with 100 microliters (µL) of 0.125-molar ethylenediamine tetraacetic acid (EDTA) (Garbarino and others, 2002). The amount of preservative was based on the assumption that the iron concentration in the sample was less than a few milligrams per liter. All samples were shipped overnight to the analyzing laboratory. Most samples were stored at ambient temperatures until they were analyzed; those for temperature-sensitive constituents which could change as a result of biological activity were maintained at 4 degrees Celsius (°C) until they were analyzed (U.S. Geological Survey, variously dated).

Radon-222 samples were collected outside the chamber using a brass sampling valve with a Teflon septum. The 10-mL sample was collected using a rinsed, glass syringe with a stainless steel needle. The needle was inserted through the septum and the valve partially closed to fill the syringe under pressure. The 10-mL sample then was injected into a USGS-prepared borosilicate glass scintillation vial prefilled with 10-mL scintillation oil. The vial was sealed with a polycone cap and shaken for 30 seconds to extract the radon into the oil, then placed in a protective cardboard tube, and shipped to the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colo.

Sample Analysis

Five laboratories analyzed samples for this study. The USGS NWQL in Lakewood, Colo., was the primary laboratory; four other laboratories were contracted by the NWQL for certain analyses. The NWQL maintains National Environmental Laboratory Accreditation Conference (NELAC) and other certifications (U.S. Geological Survey, 2010b). Samples were analyzed at the NWQL for major ions (calcium, magnesium, potassium, sodium, bromide, chloride, fluoride, silica, and sulfate), selected chemically related properties (residue on evaporation [dissolved solids] and COD), DOC, arsenic speciation, other trace elements (aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, selenium, silver, strontium, thallium, vanadium, and zinc), radon-222, and uranium. Gross alpha- and beta-particle activities and radium-226 and -228 were analyzed by Eberline Services in Richmond, Calif. Carbon isotope samples were first analyzed for the carbon-13 to carbon-12 isotopic ratio at the University of Waterloo, Isotope Laboratory, in Waterloo, Ontario, Canada. To determine the amount of carbon-14 present in the sample, inorganic carbon-bearing extracts were sent from the University of Waterloo laboratory to the University of Arizona, Physics Department Accelerator Mass Spectroscopy Laboratory in Tucson, Ariz. Tritium analyses were determined by the University of Miami, Tritium Laboratory, in Miami, Fla.

Anion concentrations were measured by ion-exchange chromatography, and major cation concentrations (along with iron concentrations) were measured by inductively coupled plasma-atomic emission spectrometry (ICP–AES) as described by Fishman (1993). DOC was measured by ultraviolet-promoted persulfated oxidation and infrared spectrometry as described by Brenton and Arnett (1993). COD was measured by a colorimetric method using dichromate oxidation as described by Fishman and Friedman (1989).

A total of 21 trace elements were analyzed. Concentrations of filtered arsenic, chromium, cobalt, copper, nickel, selenium, vanadium, and zinc were measured using collision-reaction cell inductively coupled plasma-mass spectrometry (cICP–MS) as described by Garbarino and others (2006) (table 3, at end of report). The remaining 13 trace elements (filtered aluminum, antimony, barium, beryllium, boron, cadmium, lead, lithium, manganese, molybdenum, silver, strontium, and thallium) were measured using inductively coupled plasma-mass spectrometry (ICP–MS) (Faires, 1993; Garbarino, 1999).

The arsenic species samples preserved with EDTA were separated in the laboratory using high performance liquid chromatography (HPLC) with an anion-exchange column packed with LC–SAX (Supelco) anion-exchange resin and a 50-millimoles per liter phosphate mobile phase. The arsenic concentrations of the sequential extractions then were determined by cICP–MS (Garbarino and others, 2002).

Gross alpha- and beta-particle activities were measured by a gas flow proportional planchet counting the residue on evaporation by using USEPA Method 900.0 (U.S. Environmental Protection Agency, 2008). Gross alpha- and beta-particle activities were measured at 72 hours after collection and again 30 days after collection, allowing for the measurement of the activity of short-lived isotopes (Parsa, 1998; Szabo and others, 2005). Gross alpha- and beta- particle activities are referred to as filtered, alpha or beta radioactivity, 72-hour or 30-day count, in the tables in this report. Isotopic ratios of carbon-13 to carbon-12 were determined by mass spectroscopy, and accelerator mass spectroscopy was used to determine the amount of carbon-14. Radium-226 concentration was measured by radon de-emanation by using USEPA Method 903.1 (U.S. Environmental Protection Agency, 2008). Radium-228 concentration was measured by beta-counting the actinium-228 decay product by using USEPA Method 904.0 (U.S. Environmental Protection Agency, 2008). Radon-222 concentration was measured by liquid-scintillation counting (ASTM International, 2006b). Tritium concentration was measured by electrolytic enrichment and gas counting (Ostlund and Warner, 1962). Filtered, natural uranium was measured by ICP–MS (Faires, 1993; Garbarino, 1999).

Reporting of Results

The analytical quantification procedure used by the NWQL for reporting results is based on the long-term method detection level (LT–MDL) and laboratory reporting level (LRL) (table 3). The LT–MDL concentrations are defined as a censoring limit for most analytical methods at the NWQL, and its purpose is to limit the false positive rate to less than or equal to 1 percent. An LT–MDL is a modification of the USEPA 40 Code of Federal Regulations Part 136 definition of the method detection limit (MDL). The LRL is defined as twice the LT–MDL and is established to limit the occurrence of false negative detections to less than or equal to 1 percent (Childress and others, 1999).

A constituent concentration is considered estimated by the laboratory when results are greater than the LT–MDL and less than the LRL; that is, a detection is considered likely, but quantification is considered questionable. The remark code of "E" (estimated) is assigned by the laboratory for these results. The presence of a constituent in the sample that can be verified, but the concentration is not enough to be quantified is reported as a remark code of "M." Similarly, nonzero concentration values that round to zero are converted to a null value on output and reported by using a remark code of "M" (U.S. Geological Survey, 2009).

The LRLs changed from 2007 to 2008 for some of the constituents of interest for the study. The LRL for filtered arsenic in 2007 was 0.12 μg/L, and the LRLs for the individual arsenic species were higher (0.8, 1.0, 0.6 and 1.2 micrograms arsenic per liter [μg-As/L]) for the various arsenic species—As(V), As(III), DMA, and MMA, respectively. In the second year of study, the LRLs were lowered for arsenic and As(III) to 0.06 μg/L and 0.6 μg-As/L, respectively. The LRLs for MMA increased from 1.2 μg-As/L in 2007 to 1.8 μg-As/L in 2008. There was no change in the LRL from 2007 to 2008 for DMA.

Radionuclide results are reported in picocuries per liter (pCi/L), which equals 2.22 radioactive disintegrations per minute per liter of water. As defined in Focazio and others (2001, p. v), picocuries per liter is a unit expressing the concentration (activity) of radionuclides in solution as particles emitted per unit volume (liter) of water. By definition, 1 gram of radium has 1 curie of activity. A picocurie is a millionth of a millionth of a curie. The measured activity of any single isotope is considered a concentration because a mass is linked directly to activity by the radioactive decay equation and half life. The gross activity measurements are considered activities and not concentrations because there is no identifiable half life or isotope mass associated with the measurement. The laboratory reports the unrounded values for all the radionuclide concentrations along with a 1-sigma combined standard uncertainty (CSU) and a sample-specific critical level (ssL_C), for each result. Some of the raw (unrounded) radionuclide results are reported as negative values, indicating the radiation count of the sample over the fixed interval of time when the measurement was made was less than the long-term average background radiation reported routinely by the instrument (Troyer and others, 1991). The 1-sigma CSU is a calculated measure of uncertainty of the laboratory analysis; specifically, the sum of the laboratory and counting uncertainty. By definition, the true radionuclide concentration plus or minus the 1-sigma CSU has 68-percent probability (based on 1 standard deviation of the radioactivity count) that it is within range of the reported measured value (McCurdy and others, 2008). For each radionuclide analyzed, the laboratory computes a critical level (L_C), which is the minimum quantity of a radionuclide detectable by the counting instrument that is statistically different from the instrument background or analytical blank. It is calculated from typical analytical parameter values. The ssL_C is sample specific because it is calculated for each measurement of a radionuclide constituent using the same analytical parameter values that were used during the analysis of the sample. If the measured concentration is greater than the ssL_C, it is considered a detected value. If the result is less than its associated ssL_C, a remark code of "R" is assigned to indicate that it is a nondetection (McCurdy and others, 2008). The ssL_C is like the LT–MDL for nonradioactive constituents except that the ssL_C calculations use a 5-percent error rate for false detection compared to a 1-percent error rate for false detections used for LT–MDL calculations.

For each radionuclide measurement, the laboratory calculates a sample-specific minimum detectable concentration (ssMDC), which is a performance measure for the laboratory that is approximately twice the L_C (Currie, 1968). The ssMDC is computed individually for each radionuclide sample on the basis of the instrument operating conditions at the time of the measurement and variations in background radioactivity over time (Focazio and others, 2001). In cases where the result is less than its associated ssMDC, the result is considered poorly quantified. Unlike the $ssL_{C,}$ which addresses the false detection type errors associated with the measurement, the ssMDC addresses false nondetection type errors and is computed by the laboratory after the measurement and the ssL_C criterion are calculated. The ssMDC is used by the laboratory to verify that the *a priori* minimum detectable concentration (MDC) was achieved during analysis; the *a priori* MDC is the method detection concentration calculated before the measurement is made, and is defined as the lowest concentration resulting in a 95-percent confidence level that the measured value is greater than the L_C (McCurdy and others, 2008).

The laboratory reported all the radionuclide results with an associated 1-sigma CSU and ssL_C concentration, except for samples analyzed in 2007 for radon-222 and tritium. The radon-222 and tritium concentrations measured in 2007 were reported differently because of a change in radionuclide reporting guidelines by the laboratory during the study period. For the radon-222 results, an ssMDC was reported with the result plus the 2-sigma CSU concentration. The tritium results were reported with a 2-sigma CSU and a minimum reporting level (MRL) value (superseded term previously used by the laboratory to represent the LRL). The combination of the reported environmental results for these two constituents plus or minus the 2-sigma CSU concentrations represents a 95-percent probability that the true radionuclide concentrations are within range of the reported measured value (McCurdy and others, 2008).

Quality Control

Quality control data were collected to assess the precision and accuracy of sample collection procedures and laboratory analyses (U.S. Geological Survey, variously dated). Quality control samples consisted of two equipment blank samples, two field blank samples, six sequential environmental replicate samples, and two arsenic-speciation field spike samples.

On an annual basis before the beginning of each field sampling effort, equipment blanks were collected in a controlled laboratory environment to help verify that none of the sampling equipment used to pump and filter the groundwater samples was contributing appreciable amounts of the constituents of concern measured in the environmental samples. Field blank samples were also collected in conjunction with environmental samples to ensure equipment cleaning done in the field between sites was adequate and that the collection, processing, or transporting procedures in the field did not contaminate the samples. Results for the equipment and field blank samples are listed in table 4 (at end of report).

Sequential replicate samples are collected to measure the variation in results originating from sampling and analytical methods. Sequential replicate sample results are included in tables 6, 7, and 8 (at end of report) with the environmental sample results for alkalinity, major ions, arsenic species, other trace elements, and radionuclides. Inorganic constituent replicates were collected with a new, preconditioned capsule filter. Capsule filters were replaced prior to collecting the sequential replicate in case of filter loading, which might reduce the effective pore size of the filter (Horowitz and others, 1996).

Field spike samples were collected to assess if degradation of arsenic species or matrix effects of the water created a bias for the sample results. One field spike for arsenic species was collected during each sampling season. A replicate sample was collected and spiked with a known volume (100 μL) of known concentration (2,500 μg-As/L) of arsenic species. The matrix spike recovery was calculated using instructions provided by the NWQL for each of the arsenic species analyzed (U.S. Geological Survey, 2010a). The percentage recovery of the spiked concentrations was calculated by using the following equation:

$$\text{Percentage recovery} = [(\text{Cspiked} - \text{Cunspiked})/\text{Cexpd}] * 100 \qquad (1)$$

where

Cspiked = measured result of spiked sample, in micrograms per liter;

Cunspiked = measured result of unspiked sample, in micrograms per liter; and

Cexpd = expected or theoretical concentration added to the spiked sample based on the volume and concentration of spike mixture used.

The equipment blank results indicate the sampling equipment did not introduce appreciable amounts of the constituents of interest to the samples; with a few exceptions, most of the equipment blank results were less than the applicable LRLs. Low level concentrations of calcium, DOC, barium, copper, manganese, nickel, and zinc were detected in some of the equipment blank samples (table 4). The barium result for the 2007 equipment-blank sample was reported as “M,” indicating that the constituent was detected but not quantifiable (equal to or greater than the LRL). In 2008, the concentration for barium was reported as less than the LRL. Whereas low-level concentrations of manganese, nickel, and zinc were reported as estimated values for the 2007 equipment blanks, in 2008, the equipment-blank results for these constituents were all less than the applicable LRLs. The concentration of copper in the equipment blank collected in 2007 was 0.71 μg/L, which was more than the concentration of copper measured in all but one of the 2007 environmental samples. The detection of copper in the 2007 equipment blank is more likely indicative of measurement uncertainty than the introduction of copper to the sample from the sampling equipment. Because the cICP–MS method was relatively new for copper analysis, the reporting limit for copper in 2007 was an interim reporting level (IRL), which is a temporary reporting limit used when LT–MDL data are not available, and an LRL has not yet been established (Maloney, 2005). After the laboratory completed its performance evaluation of this method for copper analysis, the LRL was set to 1.0 μg/L in 2008. The copper result was reported as less than the LRL for the equipment blank collected in 2008. Similarly, calcium was detected in the 2007 equipment blank at a concentration of 0.03 mg/L, but the laboratory raised the LRL from 0.02 to 0.04 mg/L in 2008. The concentrations of calcium measured in the environmental samples ranged from 8.23 to 66.4 mg/L. On the basis of a detected amount of calcium of 0.03 mg/L in an equipment blank, calcium concentrations in environmental samples, at most, might change by less than 1 percent as a result of calcium introduced from the sampling equipment.

The field blank results indicate the sample collection and handling procedures did not introduce appreciable contamination to the environmental samples and provided another indication that representative samples were collected from the aquifer. The field blank results included a few quantifiable results for calcium, DOC, copper, nickel, and zinc greater than their respective LRLs (table 4). A calcium concentration of 0.03 mg/L was reported in 2007 (LRL 0.02 mg/L); an estimated calcium concentration of 0.02 mg/L was reported in 2008 (LRL 0.04 mg/L). Because the concentrations measured in the field blanks were low, the results were not of concern, particularly for calcium. The calcium concentrations in the field blanks were much less than the median calcium concentration of 40.5 mg/L or the minimum concentration of 8.23 mg/L measured in the environmental samples. Estimated DOC concentrations of 0.2 and 0.3 mg/L were reported for the 2007 and 2008 field blank samples, respectively (LRL 0.4 mg/L). The DOC concentrations in the environmental samples most commonly were reported as less than 0.4 mg/L. The amounts of DOC in the field blanks were not sufficient to introduce detectable amounts of DOC to environmental samples from the sample-processing procedures done in the field. A source solution blank also was analyzed both years for DOC, and the results were reported as less than the LRL of 0.4 mg/L. The concentrations of copper, nickel, and zinc in the field blank collected in 2007 were 0.60, 0.09, and 1.1 µg/L, respectively (table 4). The LRLs for copper, nickel, and zinc were 0.40, 0.06, and 0.60 µg/L, respectively, in 2007; in 2008, the LRLs were raised to 1.0, 0.20, and 1.8 µg/L for copper, nickel and zinc, respectively. The copper concentration measured in the 2007 field blank sample was greater than concentrations measured in all but one of the 2007 environmental samples; for nickel and zinc, the concentrations in the 2007 field blank sample were equal to or greater than the concentrations in more than one-half the 2007 environmental samples. As with the equipment blanks, the field blank data indicate that the detected results from the 2007 sampling effort for these constituents might include false positives. The reporting levels for the cICP–MS method used for copper, nickel, and zinc in 2007 were IRLs, which were raised in 2008 when LRLs for these constituents were determined. Each of the concentrations measured for these three constituents in the 2008 field blank sample were reported as less than their respective LRL. Gibs and others (2000) found copper contamination in all the equipment and field blanks collected for their study at levels of about 1 µg/L or less and hypothesized that it could be from random contamination during sampling or handling in the laboratory as copper is a common aerosol and is also common wherever electrical wiring is handled. Gibs and others (2000) also reported the presence of 1 µg/L of nickel in blanks collected with a portable stainless steel submersible pump. Stainless steel connectors were used to connect sampling tubing to the public-supply well spigot, and these connectors also were used to connect different pieces of sampling equipment. Ivahnenko and others (1996) reported that zinc contamination at the 1 to 2 µg/L level occurred routinely in equipment blank samples. Blank samples prepared and analyzed at the NWQL also contained low levels of zinc (Faires, 1993). The barium result for the 2007 field blank sample was reported as “M,” indicating that the constituent was detected but not quantifiable and reported as less than the LRL in 2008 (table 4). In 2007 and 2008, the barium LRLs were 0.08 and 0.4 µg/L, respectively.

Replicate samples were compared with associated environmental samples to assess the variability of the measured concentrations by computing the relative percent difference (RPD) for each constituent with the following equation:

$$\mathrm{RPD} = |C_1 - C_2|/((C_1 + C_2)/2) \times 100, \qquad (2)$$

where

C_1 = constituent concentration, in milligrams per liter, from the environmental sample; and

C_2 = constituent concentration, in milligrams per liter, from the replicate sample.

RPDs of 10 percent or less indicate good agreement between the paired results for major ion or trace element analyses if the concentrations are sufficiently large compared to their associated LRL. RPDs for replicates with small concentrations are often large; differences between small concentrations result in large RPDs. In table 5, the minimum, average, and maximum RPDs are listed for selected constituents. An RPD was not computed for a replicated constituent if the paired results were censored as estimated or less than their associated LRL. A replicated constituent was included in table 5 if an RPD could be calculated for two or more pairs of replicate results out of the six sequential replicate samples collected during 2007–08. Some replicated constituents (chromium, cobalt, copper, lead, selenium, zinc, cabon-14, and uranium) had only one pair of replicated results where a detected amount was reported for each member of the pair; the RPDs for these replicate pairs ranged from 0 to 39 percent and these RPD results were not included in the table of minimum, average, and maximum RPDs (table 5). The RPD of 39 percent was for a zinc replicate where the concentrations were not much larger than the LRL and was the only RPD for these eight constituents that was greater than 10 percent. The minimum, average, and maximum RPDs for the remaining constituents are listed in table 5. The RPD for the major ion and trace element constituents ranged from 0 to 20 percent; vanadium, with an RPD of 20 percent, was the only constituent with an RPD greater than 10 percent. In this instance, the vanadium concentrations were not much larger than the LRL of 0.04 µg/L.

Each radionuclide concentration or activity is reported as an unrounded value along with its sample-specific laboratory analysis uncertainty. The acceptable RPD for radionuclide results was not set to a value but instead determined as acceptable if the unrounded, paired results were within 1 standard deviation (as represented by the 1-sigma CSU for each radionuclide). The RPDs for the radionuclide results ranged from 0 to 64 percent. The concentrations and activities in all but two of the radionuclide result pairs were within 1 standard deviation, indicating the results were within the uncertainty of the analysis. The two replicate pairs that were not within 1-sigma CSU were the radium-228 concentration collected on July 10, 2007, and the gross beta-particle activity (30-day count) collected on August 14, 2008; these values resulted in the two largest RPDs for radionuclides (60 and 64 percent of radium-228 concentration and gross beta-particle activity, respectively) (table 5).

Arsenic, radium, and uranium (tables 4 and 5) were the constituents of greatest concern for this report. In the field and equipment blanks, the results for each of the arsenic species and filtered arsenic were less than their respective LRLs, indicating no detectable contamination was likely introduced for any of these arsenic constituents from sample collection or laboratory analyses. The sequential replicates sufficiently reproduced the results measured in the corresponding environmental samples. The RPDs for As(III), As(V), and filtered arsenic ranged from 0 to 4.7 percent (table 5). An RPD was not calculated for DMA or MMA because all the replicate results were censored values less than the LRL.

The matrix spike recoveries for As(III) and As(V) were 83 and 84 percent, respectively for the spike sample collected in 2007. For the 2008 spike sample, the matrix spike recoveries for As(III) and As(V) were 98 and 103 percent, respectively. For the As(V) spike recovery calculation for the spike samples collected in 2007, the concentration of the unspiked sample was reported as less than the LRL of 0.8 µg-As/L. The concentration of the unspiked sample used in the calculation was the LT–MDL for As(V) of 0.4 µg-As/L. For the 2008 matrix spike calculation, the As(V) concentration of the unspiked sample was reported as an estimated value of 0.44 µg-As/L. This value was used in the spike recovery calculation and resulted in a percentage greater than 100.

Because DMA and MMA were reported as less than their associated LRLs in 2007 and 2008, the matrix spike recoveries for DMA and MMA for both years were calculated using the LT–MDL concentrations reported for these constituents. For both years, the LT–MDL of 0.3 µg-As/L was used in the calculation for DMA. For the MMA matrix spike recovery calculation, the LT–MDL concentration of 0.6 µg-As/L was used in 2007 and 0.9 µg-As/L was used in 2008. The matrix spike recoveries for the 2007 sample were 86 and 81 percent for DMA and MMA, respectively. For 2008, the matrix spike recoveries were 99 and 98 percent for DMA and MMA, respectively. Garbarino and others (2002) defined the methods for analysis of arsenic speciation in natural waters and reported percentage recoveries for field samples spiked at 50 µg-As/L that ranged from 82 to 100 percent for As(III), 97 to 102 percent for As(V), 90 to 104 percent for DMA, and 81 to 96 percent for MMA. The spike recoveries for this study were similar to those reported by Garbarino and others (2002).

Small concentrations of the radionuclides radium-226 and radium-228 were detected in the equipment blanks. In the 2007 equipment blank sample, the radium-226 result was 0.017 pCi/L with an ssL$_C$ of 0.015 pCi/L (table 4). Because the result is greater than its associated ssL$_C$, it is considered a detection, but the result is less than its associated ssMDC of 0.036 pCi/L, indicating a poorly quantified result that was likely a false detection. The lowest radium-226 concentration measured in the environmental samples was 0.204 pCi/L, which is about 10 times higher than the detected concentration in the equipment blank. Therefore, any contamination from the equipment would have had little effect on environmental sample results. In the 2008 equipment blank sample, the radium-226 and radium-228 results were greater than their associated ssL$_C$, but less than their associated ssMDC concentrations. The ssMDC for radium-226 in the 2008 equipment blank sample was 0.029 pCi/L, compared to the associated result of 0.0223 pCi/L; the ssMDC for radium-228 in the 2008 equipment blank was 0.60 pCi/L, compared to the associated result of 0.32 pCi/L. As in 2007, the radium-226 and radium-228 concentrations in the 2008 equipment blank were poorly quantified based on the performance of the method for these measurements. The laboratory noted that the critical level yield for the radium-228 result in the 2008 equipment blank was less than the contractual limit for this measurement (table 4), which further supports that this was a poorly quantified result and most likely a false detection.

The six sequential replicates analyzed for radium sufficiently reproduced the results measured in the corresponding environmental samples within the measurement precision established by the associated 1-sigma CSU (the result plus or minus the uncertainty), except for one radium-228 replicate pair. The replicate radium-228 concentration of 0.297 pCi/L was less than its associated ssMDC of 0.38 pCi/L, indicating that the result was poorly quantified. The associated environmental sample radium-228 concentration (0.96 pCi/L) met all the laboratory quality control checks.

Filtered uranium concentrations were less than the LRLs for equipment and field blanks, so it was unlikely that detectable amounts of uranium were introduced as a result of sample collection or analytical processes. RPDs for uranium are not shown in table 5 because five of the six replicate pair results were less than the LRLs. The RPD was 1 percent for the one replicate pair with detected concentrations of uranium.

Groundwater Quality

Results of the physicochemical properties, major ions, and organic carbon analyses are presented in table 6; arsenic, arsenic species, and other selected trace elements in table 7; and radionuclides in table 8. The data are listed by site number and State well number and in chronological order by the date and time of sampling. Range of concentrations and population distributions for physicochemical properties, major ions, trace elements (including arsenic and arsenic species), and radionuclides are summarized in table 9 (at end of report).

Physicochemical Properties and Major Ion Chemistry

Physicochemical properties (oxidation-reduction potential, turbidity, dissolved oxygen concentration, pH, specific conductance, temperature [air, water], alkalinity, and residue on evaporation [dissolved solids]) and major ions (calcium, magnesium, potassium, sodium, bromide, chloride, fluoride, silica, sulfate, and sulfide) varied more for some groundwater samples than for others (table 6). The ranges and median concentrations of physicochemical properties and major ion concentrations are summarized in table 9. For the environmental samples from the 28 wells sampled during the study, the range and medians of selected physicochemical properties were as follows: oxidation-reduction potential ranged from -212 to 244 mV (median -84.6 mV), pH ranged from 7.2 to 8.1 (median 7.6), specific conductance ranged from 314 to 856 microsiemens per centimeter at 25 °C (μS/cm) (median 517 μS/cm), and alkalinity ranged from 126 to 324 mg/L as calcium carbonate ($CaCO_3$) (median 167 mg/L as $CaCO_3$). The range in oxidation-reduction potential was large. The minimum value of -212 mV for oxidation-reduction potential was measured in the sample collected from well LJ–65–13–224 in 2008; such a relatively small oxidation-reduction potential indicates an environment favorable for the reduction of chemical species (Pankow, 1991). In contrast, the maximum positive value of 244 mV, measured in a sample from well LJ–65–20–513, indicates a geochemical environment with a relatively large oxidizing tendency. In samples with dissolved-oxygen concentrations less than the MRL of 0.1 mg/L, oxidation-reduction potential measurements were in the negative range except for the sample from TS–60–62–604. The dissolved-oxygen concentration in the sample from well TS–60–62–604 was considered unreliable because it did not meet stabilization criteria and failed quality-assurance logic tests (that is, it was not in agreement with other field readings); this was also the case for the dissolved-oxygen concentration measured in the sample from well LJ–60–63–604.

The dissolved-solids concentrations (filtered residue on evaporation in milligrams per liter, dried at 180 °C) ranged from 175 to 496 mg/L in the groundwater samples, with a median concentration of 294 mg/L (table 9). Of the 28 sampled wells, the maximum dissolved-solids concentration was measured in a sample collected from well LJ–65–13–222, which also had the maximum depth to the top of the screened interval (open interval, table 2). The second and third largest depths to the top of the screened interval were for wells TS–60–62–604 and LJ–65–20–421, respectively; samples from these same wells also had the second and third highest dissolved-solids concentrations, respectively.

The largest ranges in concentration for filtered major ion constituents were obtained for cations sodium and calcium and for anions chloride and bicarbonate (bicarbonate was calculated from the measured alkalinity). The ranges and medians for these constituents are as follows: 14.2 to 182 mg/L for sodium, with a median of 32.8 mg/L; 8.23 to 66.4 mg/L for calcium, with a median of 40.5 mg/L; 15.3 to 85.4 mg/L for chloride, with a median of 42.4 mg/L; and 154 to 394 mg/L for bicarbonate, with a median of 203 mg/L (table 9).

Arsenic and Other Trace Elements

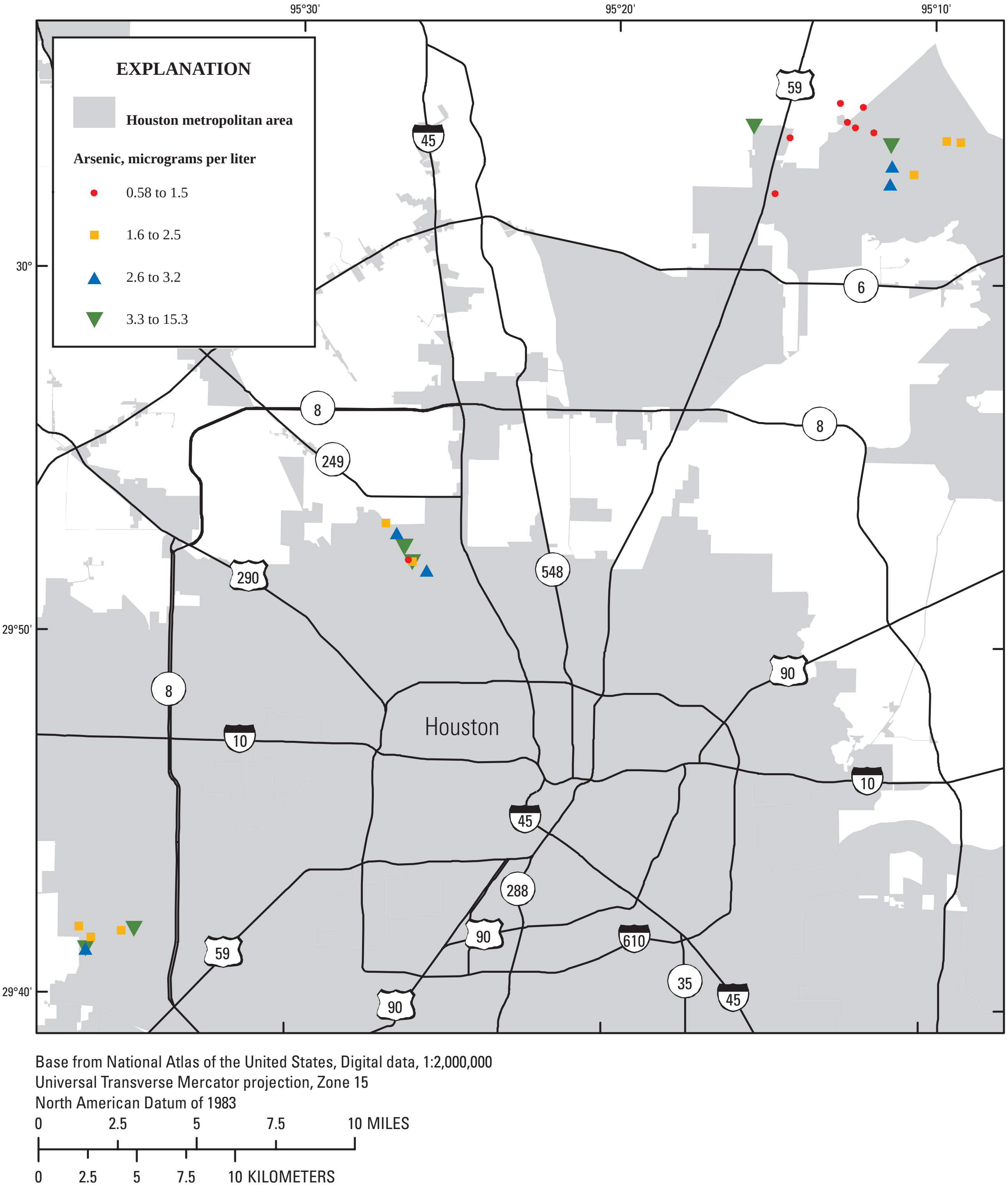
Arsenic

Arsenic concentrations measured in samples from the 28 wells ranged from 0.58 to 15.3 μg/L (table 7). The maximum concentration of arsenic (15.3 μg/L) was measured in the 2007 sample from well TS–60–62–604, which exceeded the USEPA MCL of 10 μg/L (table 1); the 2008 sample from well LJ–65–13–222 had an arsenic concentration of 10.1 μg/L, also exceeding the MCL. The geographic distribution of arsenic concentrations in the 28 sampled wells are shown in figure 3. Concentrations were grouped based on the quartiles of the dataset with the largest quartile representing results between the 75th percentile and maximum concentration. Arsenic concentrations in the largest quartile were measured in samples collected from the wells in all three areas (fig. 3).

As(III) was the most frequently detected specie of arsenic in the water with detections at 17 of the 28 sampled wells. The As(III) concentrations in the environmental samples ranged from less than 0.6 to 14.9 μg-As/L (table 7). The concentration of As(III) in three samples had estimated values of 0.3, 0.8, and 1.0 μg-As/L (less than the respective LRLs of 0.6 or 1.0 μg-As/L and equal to or greater than the LT–MDL of 0.3 or 0.5 μg-As/L). The range in concentrations for the arsenic specie As(V) was from less than 0.8 to 3.3 μg-As/L. Fourteen of the 28 sampled wells had As(V) concentrations equal to or greater than the LRL of 0.8 μg-As/L, and the remaining concentrations were less than the LRL of 0.8 μg-As/L, although two of these samples had estimated concentrations. For the organic arsenic species, DMA and MMA, the concentrations for the 28 sampled wells were all less than the respective LRLs of 0.6 μg-As/L for DMA and 1.2 to 1.8 μg-As/L for MMA (table 7), although one sample from well TS–60–62–604 had an estimated DMA concentration of 0.3 μg-As/L (less than the LRL and equal to the LT–MDL of 0.3 μg-As/L).

Other Trace Elements

The water samples collected from the 28 municipal supply wells also were analyzed for other selected trace elements (aluminum, antimony, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, selenium, silver, strontium, thallium, vanadium, and zinc) to further characterize the water chemistry (table 7). Quantifiable concentrations of barium, boron, lithium, and strontium were measured in all 28 filtered samples. Quantifiable concentrations of molybdenum were measured in 27 samples, and an estimated concentration of molybdenum was measured in 1 sample. Iron, manganese,



Base from National Atlas of the United States, Digital data, 1:2,000,000
Universal Transverse Mercator projection, Zone 15
North American Datum of 1983

Figure 3. Geographic distribution of arsenic concentrations in water samples collected from 28 municipal supply wells screened in the Gulf Coast aquifer system, Houston, Texas, 2007–08.

nickel, and vanadium were detected in 18 or more of the 28 samples. Quantifiable concentrations of chromium, cobalt, copper, lead, selenium and zinc were measured in at least 10 and in as many as 16 of the 28 samples, depending on the constituent. Aluminum concentrations equal to or greater than the LRL were measured in 5 of the 28 samples. Cadmium was detected in one sample. The concentrations of antimony, beryllium, silver, and thallium were less than their respective LRLs (table 7). Barium ranged from 110 to 408 μg/L, with a median concentration of 276 μg/L (table 9). Boron ranged from 20 to 548 μg/L, with a median concentration of 46 μg/L. Strontium ranged from 202 to 659 μg/L, with a median concentration of 318 μg/L. For those samples in which it was detected, iron ranged from less than 6 to 265 μg/L, with a median concentration of 51 μg/L, and manganese ranged from less than 0.2 to 109 μg/L, with a median concentration of 7.6 μg/L. The concentration of iron in three samples had estimated values of 4, 6, and 8 μg /L (less than the respective LRLs of 6 or 8 μg/L and greater than the LT–MDL of 3 or 4 μg/L). The concentration of manganese in two samples had estimated values of 0.1 and 0.2 μg /L (less than the respective LRL of 0.2 μg/L and greater than the LT–MDL of 0.1 μg/L).

Radionuclides

Gross Alpha-Particle and Beta-Particle Activities

Gross alpha-particle activities and beta-particle activities for all 28 samples were analyzed at 72 hours after sample collection and again at 30 days after sample collection, allowing for the measurement of the activity of short-lived isotopes. These gross activity measurements represent the overall alpha-particle and beta-particle activity of all the radionuclides present in the sample in the given period of time associated with the measurement (U.S. Environmental Protection Agency, 1997).

Radioactivity generally was detectable in the water samples. The gross alpha-particle activities measured in 26 of the 28 samples at 72 hours after sample collection were greater than their associated ssL_C (table 8). The gross alpha-particle activities ranged from R-1.1 to 17.2 pCi/L, with a median of 5.46 pCi/L (table 9); the “R” preceding the value refers to a nondetected result less than the ssL_C. The maximum gross alpha-particle activity was measured at 72 hours in the sample obtained from well LJ–65–20–422 in 2008. Because the gross alpha-particle activity measured at 30 days after collection for the same sample was the maximum 30-day activity measured in any of the 28 wells sampled, the gross alpha-particle activity for this sample could not be primarily attributed to short-lived, alpha-emitting isotopes. The gross alpha-particle activities measured after 30 days were greater than their associated ssL_C for 18 of the 28 samples collected. The gross alpha-particle activities in the samples ranged from R-0.94 to 15.5 pCi/L (table 8). Seven of the 28 sampled wells had a measured gross alpha-particle activity larger than their ssL_C at 72 hours and at 30 days, and were similar in activities at the different time intervals within the uncertainty ranges defined by the associated 1-sigma CSU. For 2 of the 28 samples, each of the alpha-particle activity counts was less than the ssL_C, indicating that there was not a measurable amount of alpha-emitting radioactivity (table 8).

Gross beta-particle activities measured at 72 hours were consistently greater than the associated ssL_C (table 8). Beta-particle activities at 72 hours ranged from 1.48 to 6.60 pCi/L, with a median of 3.26 pCi/L (table 9). The maximum beta-particle activity of 6.60 pCi/L was measured in the sample from well LJ–60–63–602. Twenty-four of the 28 samples collected had a beta-particle activity at 30 days greater than the associated ssL_C. Beta-particle activities at 30 days ranged from R-1.04 to 10.4 pCi/L, with a median of 3.25 pCi/L. The maximum gross-beta activity of 10.4 pCi/L was measured in the sample from well LJ–65–20–422. In addition to the beta-emitting isotopes in the uranium-238 and thorium-232 decay series, a substantial part of the beta-particle activity measurements in these samples could be attributed to beta emissions from potassium-40, a weak beta emitter that occurs naturally (Hem, 1992). Well LJ–60–63–602, which also had the maximum beta-particle activity measured at 72 hours, had the maximum potassium concentration of 2.67 mg/L (table 6).

Although the gross measurements of radioactivity resulted in similar activity values in most samples, 9 of the 28 sampled wells had activity measurements (at 72 hours and 30 days) greater than the ssL_C, and the activity measured at 72 hours was greater than (outside their uncertainty ranges defined by their 1-sigma CSU) the activity measured at 30 days. For the gross alpha-particle activities measured 72 hours after sample collection, four samples were equal to or greater than 14.7 pCi/L (table 8). After 30 days, only one sample had a gross alpha-particle activity greater than 15 pCi/L. When estimated uranium activities were subtracted from the gross alpha-particle activities, the uranium-corrected alpha-activity results were no longer greater than the 15 pCi/L MCL (table 1). To convert a uranium concentration in micrograms per liter to an approximate radioactivity concentration in picocuries per liter, a conversion factor of 0.68 pCi/L is used, which is based on the assumption that the uranium-234 and uranium-238 are present in equal activities. This calculation is recognized as a conservative approximation of the uranium radioactivity because the activity ratio varies in groundwater from region to region (U.S. Environmental Protection Agency, 2000). For the gross beta-particle activities, the differences were not as pronounced.

Radium

All samples collected had radium-226 concentrations greater than the associated ssL_C, and 23 of 28 radium-228 concentrations were greater than its associated ssL_C. The radium-226 concentrations measured in the samples ranged from 0.204 to 2.66 pCi/L, with a median concentration of

0.704 pCi/L (table 9). The radium-228 concentrations measured in the environmental samples ranged from R-0.18 to 1.10 pCi/L with a median of 0.47 pCi/L. To calculate the summary statistics for radionuclide results, the raw results were used. For the combined Ra, the raw results for radium-226 and radium-228 were summed, except in cases where one of the concentrations was reported as a negative result. In those cases, a zero was added to the positive concentration and a remark code of "E" was assigned to the summed result in table 9 to indicate that one of the concentrations used in the calculation was a nondetection. The combined Ra concentrations ranged from an estimated value of 0.246 to 3.23 pCi/L, with a median concentration of 1.16 pCi/L (table 9). The maximum combined Ra concentration of 3.23 pCi/L was slightly less than the USEPA MCL (5 pCi/L). The maximum combined Ra concentration was measured in the sample obtained from well LJ–60–63–511 in 2007, and the maximum radium-226 concentration also was measured in the sample from this well. The maximum radium-228 concentration was measured in a sample from well LJ–65–20–409 in 2008 (table 8). The geographic distribution of combined Ra concentrations measured in the 28 sampled wells is presented in figure 4. The distribution of concentrations was grouped based on the quartiles of the dataset with the highest range of concentrations representing results between the 75th percentile and the maximum concentration. Combined Ra concentrations in the largest quartile were measured in samples collected from wells located in all three areas (fig. 4).

Radon

All 28 samples collected had radon-222 concentrations substantially greater than the associated ssMDC for samples measured in 2007 and greater than the ssL_C for samples measured in 2008 (table 8). The radon-222 concentrations for the samples ranged from 161 to 2,230 pCi/L, with a median concentration of 550 pCi/L (table 9). Concentrations of radon-222 measured in samples from 23 of the 28 wells were equal to or greater than a proposed public drinking water standard of 300 pCi/L for unmitigated public supply wells, and none of the concentrations measured in the samples exceeded the alternative MCL of 4,000 pCi/L (U.S. Environmental Protection Agency, 1999) (table 1).

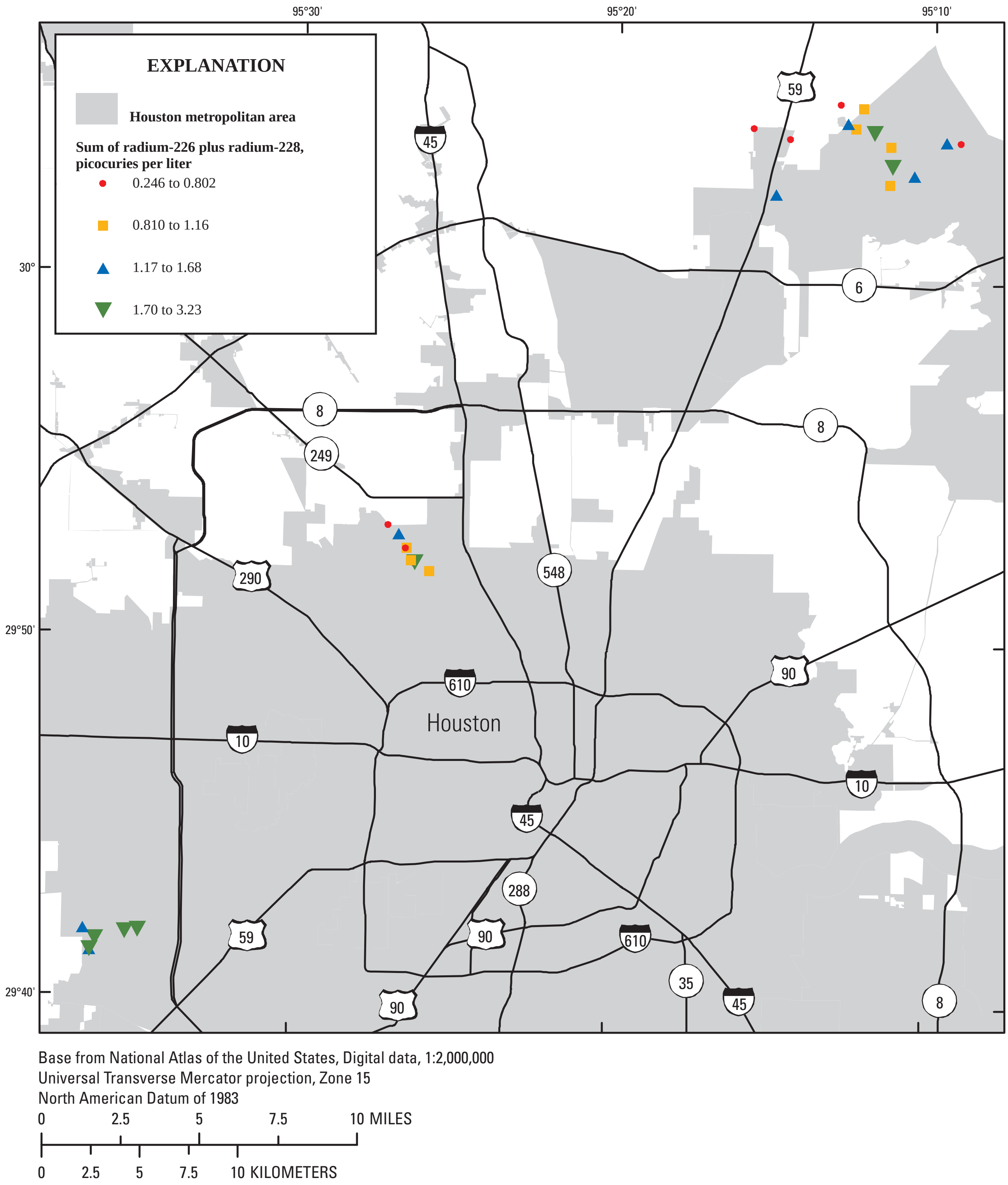
Carbon-14 and Tritium

The results of the carbon-14 analyses collected in 2008 are included in table 8 with the other radionuclide results. Nine of the 14 wells sampled in 2008 had samples submitted to the laboratory for the carbon-14 analysis plus three sequential replicates. Two of the nine samples had no measurable amount of carbon-14 present, and concentrations were reported as a less-than percentage of "modern" atmospheric carbon. Modern is defined as 95 percent of the radiocarbon activity in 1950, as defined by the standards used during analysis. The "radiocarbon" age is calibrated to this material of known age to correct for the variations in the amount of carbon-14 produced in the atmosphere; these variations mostly result from the varying intensity of cosmic rays striking the upper atmosphere and fluctuations in the amount of carbon dioxide in the atmosphere (University of Arizona, 2010). The amount of modern atmospheric carbon in the carbon-14 samples ranged from less than 0.33 to 30.73 percent. Carbon-14 can be used as a tracer to determine the relative age of recharge of groundwater; because the half life of carbon-14 is 5,730 years, carbon-14 is useful for determining the age of groundwater that was recharged between about 1,000 and 30,000 years ago (Coplen, 1993; Hinkle, 2010).

The results of the tritium analyses in the 28 samples collected also are included in table 8 with the other radionuclide results. One of the 28 samples had a detectable amount of tritium (0.42 pCi/L, measured in the sample collected from well LJ–65–13–220 on August 11, 2008). The laboratory did not provide an associated ssL_C for samples analyzed in 2007, but the unrounded results were reported with a 2-sigma CSU and associated MRL (table 8). The combination of the reported environmental results plus or minus the 2-sigma CSU concentrations represents a 95-percent probability that the true radionuclide concentrations are within range of the reported measured value. Most of the tritium results were negative, which indicates that the radiation count of the samples were less than the long-term average background radiation reported routinely by the instrument. Tritium is used as a "young" groundwater tracer; releases from aboveground testing of thermonuclear devices from 1945 through 1980 resulted in a peak in tritium concentration in the environment during the mid-1960s (Beck and Bennett, 2002). The relatively recent introduction of tritium into the environment makes tritium a useful tracer for determining relative ages of groundwater (Cook and Bohlke, 1999).

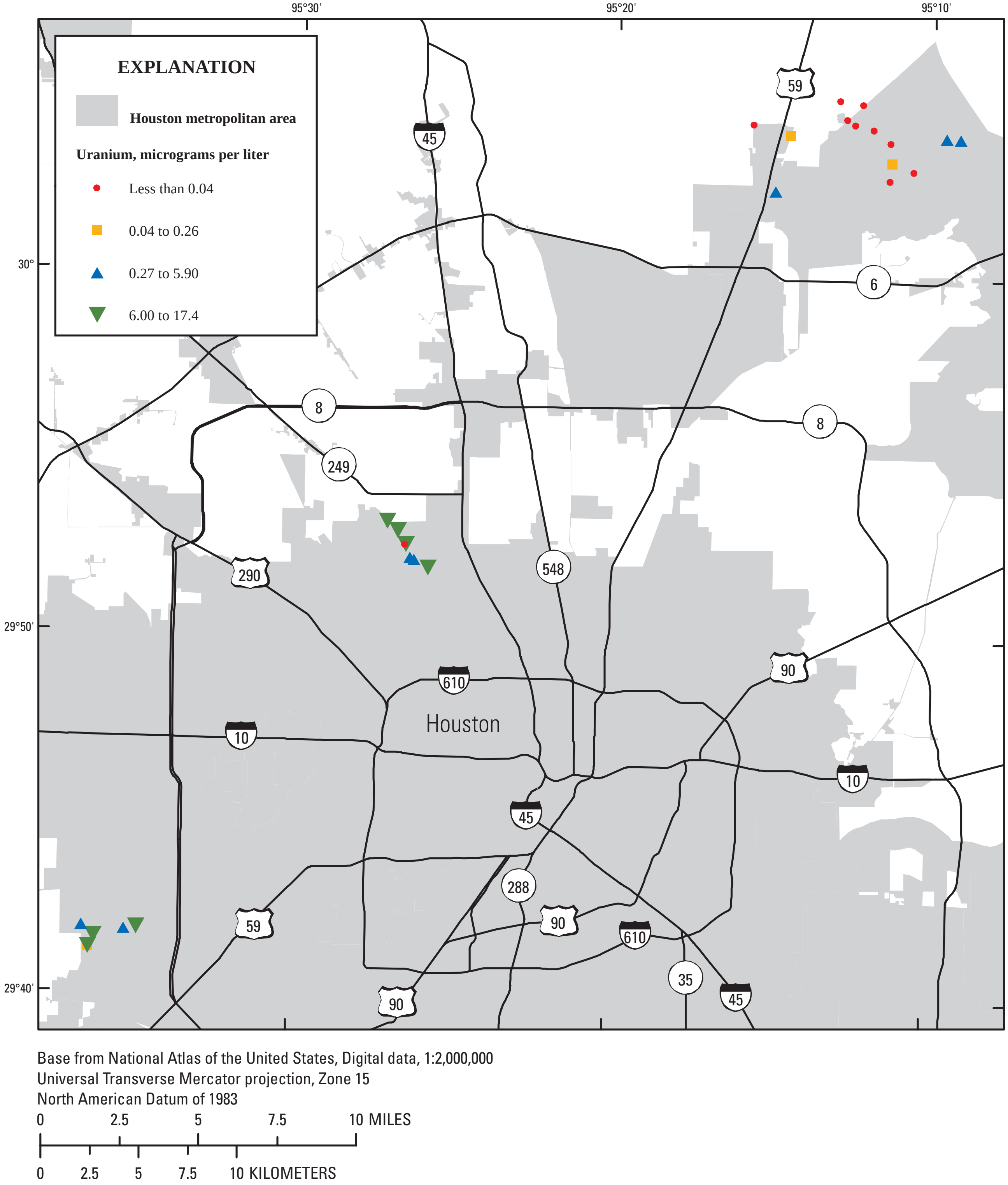
Uranium

Of the 28 samples collected, filtered uranium was detected in amounts that could be quantified in 17 samples, and qualified (estimated) in 4 samples. The uranium concentrations ranged from less than 0.02 to 17.4 μg/L, with a median concentration of 0.26 μg/L (table 9). The maximum concentration of 17.4 μg/L was measured in the sample from LJ–65–20–422. Although less than the 30 μg/L USEPA MCL for uranium, the concentration represents 58 percent of the value of the MCL. The geographic distribution of uranium concentrations measured in the 28 sampled wells is presented in figure 5. As with figures 3 and 4, the distribution of uranium concentrations was grouped based on the quartiles of the dataset with the largest quartile representing results between the 75th percentile (6.00 μg/L) and maximum concentration (17.4 μg/L). Uranium concentrations in the upper quartile were measured in samples from wells in the areas northwest and southwest of the central part of Houston (fig. 5).



Base from National Atlas of the United States, Digital data, 1:2,000,000
Universal Transverse Mercator projection, Zone 15
North American Datum of 1983

Figure 4. Geographic distribution of radium-226 plus radium-228 concentrations in water samples collected from 28 municipal supply wells screened in the Gulf Coast aquifer system, Houston, Texas, 2007–08 .



Base from National Atlas of the United States, Digital data, 1:2,000,000
Universal Transverse Mercator projection, Zone 15
North American Datum of 1983

Figure 5. Geographic distribution of uranium concentrations in water samples collected from 28 municipal supply wells screened in the Gulf Coast aquifer system, Houston, Texas, 2007–08.

Summary

During 2007–08, the U.S. Geological Survey, in cooperation with the City of Houston, Texas, completed an initial reconnaissance-level survey of naturally occurring contaminants in water samples collected from municipal supply wells in the Houston area. The purpose of this reconnaissance-level survey was to characterize source-water quality prior to drinking water treatment. This report presents the results of analyses for physicochemical (relating to physical and chemical) properties, major ions, arsenic, other trace elements, and radionuclides in water collected from 28 municipal supply wells in the Houston area, with an emphasis on arsenic, other selected trace elements, and radionuclide results.

All 28 wells that were sampled were completed in the Gulf Coast aquifer system. Twenty of the sampled wells were screened entirely in the Evangeline aquifer, and one well was screened entirely in the Chicot aquifer. The remaining seven wells contained screened intervals that intersected both aquifers. Samples were collected and processed in accordance with low-level trace-element sampling protocols established by the U.S. Geological Survey. Prior to sample collection, each well was pumped continuously for at least 1 hour to ensure that water sampled from the well was representative of water from the aquifer. Groundwater samples were collected as near to the wellhead as possible, prior to treatment. The water samples collected from the 28 municipal supply wells were analyzed for a variety of physicochemical properties and constituents to characterize the water chemistry of the Gulf Coast aquifer system. Field measurements were made of selected physicochemical properties (oxidation-reduction potential, turbidity, dissolved oxygen concentration, pH, specific conductance, water temperature, and alkalinity) and unfiltered sulfides. Samples were analyzed for major ions (calcium, magnesium, potassium, sodium, bromide, chloride, fluoride, silica, and sulfate), selected chemically related properties (residue on evaporation [dissolved solids] and chemical oxygen demand), dissolved organic carbon, arsenic species (arsenate [As(V)], arsenite [As(III)], dimethylarsinate [DMA], and monomethylarsonate [MMA]), other selected trace elements (aluminum, antimony, arsenic, barium, beryllium, boron, cadmium, chromium, cobalt, copper, iron, lead, lithium, manganese, molybdenum, nickel, selenium, silver, strontium, thallium, vanadium, and zinc), and selected radionuclides (gross alpha- and beta-particle activity [at 72 hours and 30 days], carbon-14, radium isotopes [radium-226 and radium-228], radon-222, tritium, and uranium).

Physicochemical properties, major ions, and trace elements varied considerably. Dissolved organic carbon and chemical oxygen demand were presented but not discussed in the report. The constituents have a wide range in concentrations and indicate the water quality within the aquifers is highly variable.

The physicochemical properties measured and the major ion chemistry and trace element chemistry of the groundwater sampled varied widely between the wells. The range in pH measurements for environmental samples from the 28 wells was from 7.2 to 8.1, with a median of 7.6; specific conductance measurements ranged from 314 to 856 μS/cm, with a median of 517 μS/cm; and the alkalinity measurements ranged from 126 to 324 mg/L as calcium carbonate, with a median of 167 mg/L. The range in oxidation-reduction potential measurements for the 28 wells was large, -212 to 244 mV, with a median of -84.6 mV. The largest ranges in concentration for filtered major ion constituents were observed for cations sodium and calcium and for anions chloride and bicarbonate (bicarbonate was calculated from the measured alkalinity).

Filtered arsenic was detected in all 28 samples, ranging from 0.58 to 15.3 μg/L with a median of 2.5 μg/L, and exceeded the maximum contaminant level (MCL) established by the U.S. Environmental Protection Agency of 10 μg/L in 2 of the 28 samples. Arsenic primarily occurred as trivalent arsenite (As[III]), ranging from less than 0.6 to 14.9 μg-As/L, or pentavalent arsenate (As[V]), ranging from less than 0.8 to 3.3 μg-As/L. Several other naturally occurring trace elements were detected in one-half or more of the samples. The water samples exhibited a variety of concentrations for the trace elements, and the mixtures of detected trace elements differed as well. Barium, boron, lithium, and strontium had quantifiable concentrations in all 28 filtered samples. Molybdenum had quantifiable concentrations in 27 samples and an estimated concentration in 1 sample. Iron, manganese, nickel, and vanadium were detected in 18 or more of the 28 samples, and chromium, cobalt, copper, lead, selenium, and zinc were detected in 10 to 16 of the 28 samples. Aluminum concentrations were greater than the laboratory reporting level in five samples, and cadmium was detected only once. The concentrations of antimony, beryllium, silver, and thallium were less than their respective laboratory reporting levels.

The results indicate radioactivity is generally detectable in the water samples. For the 28 samples collected, gross alpha-particle activities and beta-particle activities were measured at 72 hours and 30 days after sample collection. Gross alpha-particle activities measured at 72 hours after sample collection ranged from R-1.1 to 17.2 pCi/L and at 30 days ranged from R-0.94 to 15.5 pCi/L (“R” indicates nondetected result less than the sample-specific critical level [ssL_c]). Gross beta-particle activities measured at 72 hours ranged from 1.48 to 6.60 pCi/L and at 30 days ranged from R-1.04 to 10.4 pCi/L. Although the gross measurements of radioactivity resulted in similar activity values in most samples, 9 of the 28 sampled wells had a concentration (measured at 72 hours and 30 days) greater than the ssL_C, and the activity measured at 72 hours was greater than (outside their uncertainty ranges defined by their 1-sigma combined standard uncertainty) the activity measured at 30 days. For the gross alpha-particle activities measured in the samples collected, 26 of the 28 samples had alpha-particle activities measured at 72 hours that exceeded the associated ssL_C, and 4 were equal to or greater than 14.7 pCi/L. After 30 days, only one sample had a gross alpha-particle activity greater than 15 pCi/L. The uranium-corrected alpha-activity results were no longer greater than the 15 pCi/L

MCL. For the gross beta-particle activities measured in the samples, all the samples collected had a beta-particle activity (measured at 72 hours) greater than the associated ssL_C. All the samples had detectable concentrations of radium-226 and greater than one-half had detectable concentrations of radium-228. The combined radium concentrations ranged from an estimated value of 0.246 to 3.23 pCi/L, with a median of 1.16 pCi/L; the maximum concentration of 3.23 pCi/L did not exceed the MCL of 5 pCi/L. Concentrations of radon-222 measured in all samples ranged from 161 to 2,230 pCi/L (median 550 pCi/L), and concentrations in samples from 23 of the 28 wells were equal to or greater than a proposed public drinking water standard of 300 pCi/L for unmitigated public supply wells. Two of the nine samples submitted to the laboratory for the carbon-14 analysis had no measurable amount of carbon-14 present, and concentrations were reported as a less-than percentage of modern atmospheric carbon. The carbon-14 measured in the 28 samples ranged from less than 0.33 to 30.73 percent of modern carbon. Only 1 of the 28 samples had a measurable amount of tritium. Filtered uranium concentrations ranged from less than 0.02 to 17.4 µg/L (median 0.26 µg/L; the maximum concentration of 17.4 µg/L did not exceed the MCL of 30 µg/L.

References

Abernathy, R.L.C., and Chappell, W.R., eds., 1997, Arsenic—Exposure and health effects: London, Chapman Hall, 429 p.

American Public Health Association, American Water Works Association, and Water Pollution Control Federation, 2005, Standard methods for the examination of water and wastewater (21st ed.): Washington, D.C., American Public Health Association, [variously paged].

ASTM International, 2006a, D1193–06, Standard specification for reagent water: ASTM International, accessed November 17, 2009, at *http://www.astm.org/Standards/D1193.htm*.

ASTM International, 2006b, D5072–98, Standard test method for radon in drinking water: ASTM International, accessed August 20, 2008, at *http://www.astm.org*.

Baker, E.T., Jr., 1979, Stratigraphic and hydrogeologic framework of part of the Coastal Plain of Texas: Texas Department of Water Resources Report 236, 43 p.

Beck, H.L., and Bennett, B.G., 2002, Historical overview of atmospheric nuclear weapons testing and estimates of fallout in the continental United States: Health Physics, v. 82, no. 5, p. 591–608.

Brenton, R.W., and Arnett, T.L., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of dissolved organic carbon by uv-promoted persulfate oxidation and infrared spectrometry: U.S. Geological Survey Open-File Report 92–480, 12 p.

CHEMetrics, 2008, Operator's manual V–2000 photometer (Rev. 7): CHEMetrics Inc., 21 p.

Childress, C.J.O., Foreman, W.T., Connor, B.F., and Maloney, T.J., 1999, New reporting procedures based on long-term method detection levels and some considerations for interpretations of water-quality data provided by the U.S. Geological Survey National Water Quality Laboratory: U.S. Geological Survey Open-File Report 99–193, 19 p.

Chowdhury, A.H., Boghici, Radu, and Hopkins, Janie, 2006, Hydrochemistry, salinity distribution, and trace constituents—Implications for salinity sources, geochemical evolution, and flow systems characterization, Gulf Coast aquifer, Texas, *in* Mace, R.E., Davidson, S.C., Angle, E.S., and Mullican, W.F., eds., Aquifers of the Gulf Coast of Texas: Texas Water Development Board Report 365, p. 81–128.

Cook, P.G., and Böhlke, J.K., 1999, Determining timescales for groundwater flow and solute transport, *in* Cook, P.G., and Herczeg, A., eds., Environmental tracers in subsurface hydrology, chap. 1: Amsterdam, Kluwer Academic Press, p. 1–30.

Coplen, T.B., 1993, Uses of environmental isotopes, *in* Alley, W.M., ed., Regional ground-water quality: New York, Van Nostrand Reinhold, p. 227–254.

Currie, L.A., 1968, Limits for qualitative detection and quantitative determination—Application to radiochemistry: Analytical Chemistry, v. 20, p. 586–593.

DeSimone, L.A., 2009, Quality of water from domestic wells in principal aquifers of the United States, 1991–2004: U.S. Geological Survey Scientific Investigations Report 2008–5227, 139 p., accessed September 25, 2010, at *http://pubs.usgs.gov/sir/2008/5227*.

Faires, L.M., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of metals in water by inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 92–634, 28 p.

Fishman, M.J., ed., 1993, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of inorganic and organic constituents in water and fluvial sediments: U.S. Geological Survey Open-File Report 93–125, 217 p.

Fishman, M.J., and Friedman, L.C., 1989, Methods for determination of inorganic substances in water and fluvial sediments: U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1, 545 p., Method ID: I–3561–89.

Focazio, M.J., Welch, A.H., Watkins, S.A., Helsel, D.R., and Horn, M.A., 2000, A retrospective analysis on the occurrence of arsenic in ground-water resources of the United States and limitations in drinking-water-supply characterizations: U.S. Geological Survey Water-Resources Investigation Report 99–4279, 21 p.

Focazio, M.J., Szabo, Zoltan, Kraemer, T.F., Mullin, A.H., Barringer, T.H., and dePaul, V.T., 2001, Occurrence of selected radionuclides in ground water used for drinking water in the United States—A reconnaissance survey, 1998: U.S. Geological Survey Water-Resources Investigation Report 00–4273, 39 p.

Garbarino, J.R., 1999, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Determination of dissolved arsenic, boron, lithium, selenium, strontium, thallium, and vanadium using inductively coupled plasma-mass spectrometry: U.S. Geological Survey Open-File Report 99–093, 31 p.

Garbarino, J.R., Bednar, A.J., and Burkhardt, M.R., 2002, Methods of analysis by the U.S. Geological Survey National Water Quality Laboratory—Arsenic speciation in natural-water samples using laboratory and field methods: U.S. Geological Survey Water-Resources Investigations Report 02–4144, 40 p.

Garbarino, J.R., Kanagy, L.K., and Cree, M.E., 2006, Determination of elements in natural-water, biota, sediment and soil samples using collision/reaction cell inductively coupled plasma-mass spectrometry: U.S. Geological Survey Techniques and Methods, book 5, sec. B, chap.1, 88 p.

Gibs, Jacob, Szabo, Zoltan, Ivahnenko, Tamara, and Wilde, F.D., 2000, Change in field turbidity and trace element concentrations during well purging: Ground Water, v. 38, no. 4, p. 577–588.

Hach Company, 2007, Sulfide, method 8131: DR 2800 Spectrophotometer Procedures Manual Edition 2, p. 757–760.

Hansen, H.J., 1971, Transmissivity tracts in the coastal plain aquifers of Maryland: Southeastern Geology, v. 13, p. 127–149.

Hem, H.D., 1992, Study and Interpretation of the chemical characteristics of natural water: U.S. Geological Survey Water-Supply Paper 2254, 264 p.

Hinkle, S.R., 2010, Age of groundwater: Water Encyclopedia, accessed August 9, 2010, at *http://www.waterencyclopedia.com/Ge-Hy/Groundwater-Age-of.html*.

Horowitz, A.J., Lum, K.R., Garbarino, J.R., Hall, G.E.M., LeMieux, C., and Demas, C.R., 1996, Problems associated with using filtration to define dissolved trace element concentrations in natural water samples: Environmental Science Technology, v. 30, no. 3, p. 954–963.

Ivahnenko, Tamara, Szabo, Zoltan, and Hall, G.S., 1996, Use of an ultra-clean sampling technique with inductively coupled plasma-mass spectrometry to determine trace-element concentrations in water from the Kirkwood-Cohansey aquifer system, Coastal Plain, New Jersey: U.S. Geological Survey Open-File Report 96–142, 37 p.

Kasmarek, M.C., Houston, N.A., and Ramage, J.K., 2009, Water-level altitudes 2009 and water-level changes in the Chicot, Evangeline, and Jasper aquifers and compaction 1973–2008 in the Chicot and Evangeline aquifers, Houston-Galveston region, Texas: U.S. Geological Survey Scientific Investigations Map 3081, 3 p., 16 sheets, 2 appendixes.

Lewis, M.E., June 2006, Dissolved oxygen (version 2.1): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6, sec. 6.2, accessed August 20, 2008, at *http://pubs.water.usgs.gov/twri9A6/*.

Maloney, T.J., ed., 2005, Quality management system, U.S. Geological Survey National Water Quality Laboratory: U.S. Geological Survey Open-File Report 2005–1263, version 1.3, chapters and appendixes variously paged.

McCurdy, D.E., Garbarino, J.R., and Mullin, A.H., 2008, Interpreting and reporting radiological water-quality data: U.S. Geological Survey Techniques and Methods, book 5, chap. B6, 33 p.

Michel, T.A., 2006, 100 Years of groundwater use and subsidence in the upper Texas Gulf Coast, *in* Mace, R.E., Davidson, S.C., Angle, E.S., and Mullican, W.F., eds., Aquifers of the Gulf Coast of Texas: Texas Water Development Board Report 365, chap. 7, p. 139–148.

National Research Council, 1999, Arsenic in drinking water: Washington, D.C., National Academy Press, 273 p.

Ostlund, H.G., and Warner, E., 1962, Electrolytic enrichment of tritium and deuterium for natural tritium measurements, *in* Tritium in the physical and biological sciences: Vienna, Austria, International Atomic Energy Agency, v. 1, p. 96–104.

Pankow, J.F., 1991, Aquatic chemistry concepts: Chelsea, Mich., Lewis Publishers, 683 p.

Parsa, Bahman, 1998, Contribution of short-lived radionuclides to alpha-particle radioactivity in drinking water and their impact on the Safe Drinking Water Act Regulations: Radioactivity and Radiochemistry, v. 9, no. 4, p. 41–50.

Renken, R.A., 1998, Ground water atlas of the United States—Segment 5, Arkansas, Louisiana, and Mississippi: U.S. Geological Survey Hydrologic Atlas 730–F, accessed August 20, 2008, at *http://capp.water.usgs.gov/gwa/ch_f/F-text3.html*.

Ryder, P.D., 1996, Ground water atlas of the United States: Segment 4, Oklahoma, Texas: U.S. Geological Survey Hydrologic Atlas 730–E, accessed August 20, 2008, at *http://capp.water.usgs.gov/gwa/ch_e/E-text6.html*.

Ryder, P.D. and Ardis, A.F., 2002, Hydrology of the Texas Gulf Coast aquifer systems: U.S. Geological Survey Professional Paper 1416–E, 77 p.

Ryker, S.J., 2003, Arsenic in ground water used for drinking water in the United States, *in* Welch, A.H., and Stollenwerk, K.G., eds., Arsenic in ground water geochemistry and occurrence: Amsterdam, Kluwer Academic Publishers, p. 165–178.

Smedley, P.L., and Kinninburgh, D.G., 2002, A review of the source, behavior and distribution of As in natural waters: Applied Geochemistry, v. 17, p. 517–568.

Sugarman, P.J., and Miller, K.G., 1997, Correlation of Miocene sequences and hydrogeologic units, New Jersey Coastal Plain: Sedimentary Geology, v. 108, p. 3–18.

Szabo, Zoltan, dePaul, V.T., Kraemer, T.F., and Parsa, Bahman, 2005, Occurrence of radium-224, radium-226, and radium-228 in water of the unconfined Kirkwood-Cohansey aquifer system, southern New Jersey: U.S. Geological Survey Scientific Investigations Report 2004–5224, 84 p. (Also available at *http://pubs.usgs.gov/sir/2004/5224*.)

Texas State Data Center, 2007, Estimates of the total population of counties and places in Texas for July 1, 2006 and January 1, 2007: Texas Population Estimates and Projections Program, accessed February 14, 2008, at *http://txsdc.utsa.edu/tpepp/2006_txpopest_msa.php*.

Troyer, G.L., Jones, R.A., and Jensen, Louis, 1991, The utility of reporting negative counting values: Radioactivity and Radiochemistry, v. 2, no. 1, p. 48–56.

University of Arizona, 2010, Accelerator mass spectrometry laboratory, basic principles of radiocarbon dating: accessed September 15, 2010, at *http://www.physics.arizona.edu/ams/education/theory.htm*.

U.S. Environmental Protection Agency, 1997, National primary drinking water regulations—Analytical methods for radionuclides: Federal Register, v. 62, no. 43, p. 10,168–10,175.

U.S. Environmental Protection Agency, 1999, National primary drinking water regulations—Radon-222; Proposed Rule 40 CFR Parts 141 and 142: Washington D.C., Federal Register, v. 64, no. 211, p. 59,245–59,294.

U.S. Environmental Protection Agency, 2000, National primary drinking water regulations—Radionuclides; Final Rule 40 CFR Parts 9, 141, and 142: Washington, D.C., Federal Register, v. 65, no. 236, p. 76,708–76,753.

U.S. Environmental Protection Agency, 2001, National primary drinking water regulations—Arsenic and clarification to compliance and new source contaminants monitoring; Final Rule 40 CFR Parts 141 and 142: Washington, D.C., Federal Register, v. 66, no. 14, p. 6,975–7,066.

U.S. Environmental Protection Agency, 2008, Analytical methods approved for drinking water compliance monitoring of radionuclides: accessed August 20, 2008, at *http://www.epa.gov/safewater/methods/pdfs/methods/methods_radionuclides.pdf.*

U.S. Environmental Protection Agency, 2010, Radionuclides in drinking water rule: accessed August 27, 2010, at *http://www.epa.gov/safewater/radionuclides/regulation.html*.

U.S. Geological Survey, 2009, User's manual for the National Water Information System of the U.S. Geological Survey—Water-quality system (version 4.9): accessed November 18, 2009, at *http://nwis.usgs.gov/nwisdocs4_9/qw/QW.user.book.html*.

U.S. Geological Survey, 2010a, National Water Quality Laboratory—Calculation of matrix spike recovery: accessed August 26, 2010, at *http://wwwnwql.cr.usgs.gov/dyn.shtml?SpikeCalc*.

U.S. Geological Survey, 2010b, National Water Quality Laboratory—Quality: accessed August 25, 2010, at *http://nwql.usgs.gov/Public/quality.shtml.*

U.S. Geological Survey, variously dated, National field manual for the collection of water-quality data: U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chaps. A1–A9, accessed September 27, 2010, at *http://pubs.water.usgs.gov/twri9A.*

Welch, A.H., Westjohn, D.B., Helsel, D.R., and Wanty, R.B., 2000, Arsenic in ground water of the United States—Occurrence and geochemistry: Ground Water, v. 38, no. 4, p. 589–604

Wilde, F.D., and Radtke, D.B., 2005, General information and guidelines (version 1.2): U.S. Geological Survey Techniques of Water-Resources Investigations, book 9, chap. A6., section 6.0, accessed August 20, 2008, at *http://pubs.water.usgs.gov/twri9A6/*.

Table 2. Well information for municipal supply wells sampled in the Houston, Texas, area, 2007–08.

[ft bls, feet below land surface; 121EVGL, Evangeline aquifer; CLSD, clay sand; SDCL, sand clay; --, no data available; 112CEVG, Chicot and Evangeline aquifers; 112CHCT, Chicot aquifer]

U.S. Geological Survey site number	State well number	County	Well depth (ft bls)	Depth to top of open interval (ft bls)	Depth to bottom of open interval (ft bls)	Date of construction	Aquifer code	Lithologic code
Wells sampled in 2007								
300419095154301	TS–60–62–604	Montgomery	1,465	1,164	1,179	10/23/1982	121EVGL	CLSD
				1,199	1,239			
				1,289	1,299			
				1,314	1,344			
				1,364	1,382			
				1,384	1,422			
				1,424	1,450			
300258095145301	TS–60–63–404	Montgomery	1,046	790	802	8/1/1984*	121EVGL	SDCL
				850	870			
				888	932			
				954	980			
				990	1,000			
				1,020	1,036			
300359095122902	LJ–60–63–510	Harris	832	782	821	3/17/1981	121EVGL	--
300302095113301	LJ–60–63–511	Harris	1,044	662	718	12/1/1981*	121EVGL	SDCL
				730	798			
				828	838			
				850	870			
				982	1,002			
				1,008	1,024			
300355095093501	LJ–60–63–602	Harris	1,160	744	878	5/16/1990	121EVGL	SDCL
				940	946			
				1,008	1,070			
				1,088	1,140			
300225095144202	LJ–60–63–709	Harris	965	725	736	1/21/1982	121EVGL	SDCL
				818	880			
				908	960			
				718	953			
300231095113701	LJ–60–63–508	Harris	918	664	714	4/2/1990	121EVGL	SDCL
				724	798			
				830	898			

Table 2. Well information for municipal supply wells sampled in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	County	Well depth (ft bls)	Depth to top of open interval (ft bls)	Depth to bottom of open interval (ft bls)	Date of construction	Aquifer code	Lithologic code
300334095113401	LJ–60–63–504	Harris	1,100	657	710	7/29/1983	121EVGL	SDCL
				730	790			
				834	876			
				940	954			
				984	1,034			
				1,070	1,080			
300403095125402	LJ–60–63–502	Harris	839	747	765	3/17/1981	121EVGL	SDCL
				776	792			
				802	818			
				822	828			
300426095123902	LJ–60–63–407	Harris	827	732	770	3/17/1981	121EVGL	SDCL
				780	795			
				800	820			
300408095115201	LJ–60–63–503	Harris	1,060	860	940	3/14/1980	121EVGL	--
				1,000	1,045			
300446095121901	TS–60–63–507	Montgomery	1,190	850	914	10/19/1987	121EVGL	SDCL
				1,096	1,132			
				1,160	1,170			
300343095090301	LJ–60–63–604	Harris	1,130	748	771	2/3/1998	121EVGL	SDCL
				788	808			
				814	830			
				852	857			
				879	884			
				905	910			
				931	936			
				959	964			
				1,004	1,046			
				1,050	1,058			
				1,075	1,100			
				1,103	1,108			
300248095105301	LJ–60–63–505	Harris	1,136	730	790	2/25/1988	121EVGL	SDCL
				800	810			
				846	870			
				950	956			
				980	1,016			
				1,044	1,070			
				1,088	1,116			

Table 2. Well information for municipal supply wells sampled in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	County	Well depth (ft bls)	Depth to top of open interval (ft bls)	Depth to bottom of open interval (ft bls)	Date of construction	Aquifer code	Lithologic code
				Wells sampled in 2008				
294113095361701	LJ–65–20–421	Harris	1,667	1,081	1,114	11/5/1997	121EVGL	SDCL
				1,138	1,144			
				1,168	1,174			
				1,198	1,204			
				1,230	1,274			
				1,296	1,304			
				1,330	1,342			
				1,346	1,378			
				1,402	1,408			
				1,432	1,488			
				1,516	1,522			
				1,554	1,560			
				1,586	1,602			
				1,618	1,642			
294113095361702	LJ–65–20–422	Harris	995	660	691	2/27/1998	112CEVG	SDCL
				718	743			
				776	846			
				852	906			
				930	940			
				954	968			
294131095360701	LJ–65–20–407	Harris	1,650	618	636	5/1/1970*	112CEVG	SDCL
				648	692			
				700	708			
				730	746			
				790	820			
				828	896			
				940	962			
				994	1,002			
				1,082	1,120			
				1,246	1,304			
				1,340	1,376			
				1,424	1,450			
				1,466	1,478			
				1,504	1,520			
				1,570	1,604			
				1,616	1,634			

Table 2. Well information for municipal supply wells sampled in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	County	Well depth (ft bls)	Depth to top of open interval (ft bls)	Depth to bottom of open interval (ft bls)	Date of construction	Aquifer code	Lithologic code
294147095344303	LJ–65–20–513	Harris	1,407	649	672	4/7/1997	112CEVG	--
				685	705			
				710	747			
				757	771			
				784	793			
				802	815			
				842	860			
				868	910			
				924	960			
				1,090	1,108			
				1,122	1,139			
				1,163	1,187			
				1,215	1,225			
				1,277	1,293			
				1,339	1,356			
				1,369	1,399			
294144095351002	LJ–65–20–409	Harris	1,445	615	640	12/19/1977	112CEVG	--
				669	698			
				728	752			
				804	865			
				877	889			
				904	916			
				928	978			
				1,004	1,020			
				1,065	1,087			
				1,206	1,222			
294149095363002	LJ–65–20–408	Harris	1,550	643	667	3/21/1983	112CEVG	--
				705	724			
				757	872			
				903	932			
				976	987			
				1,069	1,105			
				1,143	1,163			
				1,183	1,200			
				1,222	1,254			
				1,268	1,286			
				1,318	1,372			
				1,453	1,463			
				1,481	1,505			
				1,519	1,529			

Table 2. Well information for municipal supply wells sampled in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	County	Well depth (ft bls)	Depth to top of open interval (ft bls)	Depth to bottom of open interval (ft bls)	Date of construction	Aquifer code	Lithologic code
295228095262901	LJ–65–13–220	Harris	1,668	613	663	8/1/1970*	112CEVG	--
				683	733			
				773	903			
				958	1,028			
				1,058	1,073			
				1,178	1,193			
				1,238	1,273			
				1,403	1,418			
				1,468	1,498			
				1,513	1,533			
				1,573	1,583			
				1,628	1,653			
295228095263101	LJ–65–13–222	Harris	1,661	1,168	1,190	2/10/1995	121EVGL	SDCL
				1,210	1,216			
				1,234	1,278			
				1,298	1,306			
				1,326	1,333			
				1,354	1,362			
				1,382	1,412			
				1,432	1,437			
				1,457	1,463			
				1,482	1,523			
				1,535	1,539			
				1,551	1,597			
				1,613	1,641			
295207095262102	LJ–65–13–221	Harris	565	321	383	1/18/1993	112CHCT	--
				395	407			
				429	439			
				486	528			
				533	556			
295306095270502	LJ–65–05–813	Harris	1,480	601	621	6/27/1984	121EVGL	--
				651	686			
				736	802			
				807	817			
				821	830			
				841	901			
				917	932			
				942	957			

Table 2. Well information for municipal supply wells sampled in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	County	Well depth (ft bls)	Depth to top of open interval (ft bls)	Depth to bottom of open interval (ft bls)	Date of construction	Aquifer code	Lithologic code
295306095270502—Continued				972	991			
				1,127	1,157			
				1,174	1,186			
				1,232	1,242			
				1,362	1,417			
				1,450	1,470			
295150095254601	LJ–65–13–214	Harris	1,507	644	673	3/7/1968	112CEVG	--
				705	747			
				799	823			
				833	979			
				990	1,029			
				1,040	1,074			
				1,084	1,099			
				1,109	1,128			
				1,199	1,233			
				1,274	1,284			
				1,304	1,343			
				1,418	1,493			
295251095264502	LJ–65–05–814	Harris	1,698	648	699	5/25/1984	121EVGL	--
				738	778			
				788	812			
				838	874			
				887	907			
				923	937			
				942	974			
				982	1,012			
				1,088	1,108			
				1,128	1,163			
				1,188	1,223			
				1,238	1,254			
				1,408	1,429			
				1,470	1,498			
				1,605	1,618			
				1,655	1,689			
295203095261401	LJ–65–13–224	Harris	1,635	1,072	1,116	11/28/1995	121EVGL	SDCL
				1,138	1,146			
				1,168	1,176			
				1,198	1,222			

Table 2. Well information for municipal supply wells sampled in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	County	Well depth (ft bls)	Depth to top of open interval (ft bls)	Depth to bottom of open interval (ft bls)	Date of construction	Aquifer code	Lithologic code
295203095261401—Continued				1,242	1,272			
				1,294	1,302			
				1,324	1,332			
				1,354	1,362			
				1,382	1,390			
				1,412	1,428			
				1,434	1,474			
				1,496	1,520			
				1,530	1,560			
				1,576	1,584			
				1,598	1,610			
295204095261301	LJ–65–13–225	Harris	1,075	714	736	12/22/1995	121EVGL	SDCL
				756	764			
				784	796			
				800	818			
				838	928			
				940	953			
				957	1,006			
				1,010	1,030			
				1,034	1,050			

[*] The day of the date of construction was not reported, so the first day of the month was assigned arbitrarily.

Table 3. Laboratory reporting levels and analytical methods used for water samples collected from selected municipal supply wells in the Houston, Texas, area, 2007–08.

[mg/L, milligrams per liter; °C, degrees Celsius; mV, millivolts; µS/cm, microsiemens per centimeter at 25 °C; NTRU, Nephelometric Turbidity Ratio Unit; µg-As/L, micrograms arsenic per liter; µg/L, micrograms per liter; EDTA, ethylenediamine tetraacetic acid; ICP–MS, inductively coupled plasma-mass spectrometry; cICP–MS, collision-reaction cell inductively coupled plasma-mass spectrometry; ICP–AES, inductively coupled plasma-atomic emission spectrometry; pCi/L, picocuries per liter; USEPA, U.S. Environmental Protection Agency]

Constituent	Laboratory reporting level	Method
Water properties, major ion chemistry		
Major anions	0.02–.2 mg/L	Ion chromatography
Temperature	.1 °C	Field meter
pH	.1 standard unit	
Dissolved oxygen	.1 mg/L	
Oxidation-reduction potential	mV + 20	
Specific conductance	5 µS/cm	
Turbidity	.1 NTRU	
Alkalinity	.1 mg/L	Titration
Dissolved organic carbon	.4 mg/L	Persulfated oxidation and infrared spectrometry
Chemical oxygen demand	10 mg/L	Colorimetry with dichromate oxidation
Arsenic and trace elements		
Arsenic species	.6–1.8 µg-As/L	EDTA preservation; ICP–MS
Arsenic, other trace elements	.02–1.8 µg/L	cICP–MS
Trace elements	.01–1.8 µg/L	ICP–MS
Major cations and iron	4-8 µg/L	ICP–AES
Radionuclides		
Gross alpha, beta; short-term (48-hour) and long-term repeat analysis (30-day)	3 pCi/L	Evaporation and low-background proportional count
Radium-226	.1 pCi/L	Barium-sulfate coprecipitation and radon de-emanation (USEPA Method 903.1[1])
Radium-228	.5 pCi/L	Barium-sulfate coprecipitation and beta-count of actinium-228 (USEPA Method 904.0[1])
Radon-222	40 pCi/L	Alpha scintillometry
Uranium	.02 µg/L	ICP–MS

[1] U.S. Environmental Protection Agency (2008).

Table 4. Results of major ion, trace element, and radionuclide analyses from quality control samples, equipment blanks, and field blanks, collected in association with municipal supply wells sampled in the Houston, Texas, area, 2007–08.

[USGS TWSC, U.S. Geological Survey Texas Water Science Center; mg/L, milligrams per liter; <, less than; E, estimated; °C, degrees Celsius; DOC, dissolved organic carbon; µg/L, micrograms per liter; µg-As/L, micrograms arsenic per liter; --, no data available; M, presence verified but not quantified; Th, thorium; pCi/L, picocuries per liter; CSU, combined standard uncertainty; ssL_C, sample-specific critical level; Cs, cesium; R, nondetected result less than ssL_C; d, yield outside contractually acceptable range]

U.S. Geological Survey site number	Site name or State well number	Date	Sample start time	Sample type	Calcium, water, filtered (mg/L)	Magnesium, water, filtered (mg/L)	Potassium, water, filtered (mg/L)	Sodium, water, filtered, (mg/L)	Bromide, water, filtered (mg/L)	Chloride, water, filtered (mg/L)	Fluoride, water, filtered (mg/L)	Silica, water, filtered (mg/L as SiO_2)
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	6/4/2007	1359	Equipment blank	0.03	<0.014	<0.04	<0.20	<0.02	<0.12	<0.10	<0.02
300359095122902	LJ–60–63–510	6/26/2007	0859	Field blank	.03	<.014	<.04	<.20	<.02	<.12	<.10	<.02
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	8/4/2008	1059	Equipment blank	<.04	<.020	<.02	<.12	<.02	<.12	<.12	<.02
295228095262901	LJ–65–13–220	8/11/2008	0959	Field blank	E.02	<.020	<.02	<.12	<.02	<.12	<.12	<.02

U.S. Geological Survey site number	Site name or State well number	Date	Sample start time	Sample type	Sulfate, water, filtered (mg/L)	Residue on evaporation, dried at 180 °C, water, filtered (mg/L)	Organic carbon (DOC), water, filtered (mg/L)	Chemical oxygen demand (COD), high level, water, unfiltered (mg/L)	Aluminum, water, filtered (µg/L)	Antimony, water, filtered (µg/L)	Arsenate ($H_2AsO_4^-$, As[V]), water, filtered (µg-As/L)	Arsenic, water, filtered (µg/L)
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	6/4/2007	1359	Equipment blank	<0.18	<10	<0.4	--	<1.6	<0.06	<0.8	<0.12
300359095122902	LJ–60–63–510	6/26/2007	0859	Field blank	<.18	<10	E.2	<10	<1.6	<.06	<.8	<.12
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	8/4/2008	1059	Equipment blank	<.18	<10	E.2	<10	<1.6	<.14	<.8	<.06
295228095262901	LJ–65–13–220	8/11/2008	0959	Field blank	<.18	<10	E.3	<10	<1.6	<.14	<.8	<.06

Table 4. Results of major ion, trace element, and radionuclide analyses from quality control samples, equipment blanks, and field blanks, collected in association with municipal supply wells sampled in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	Site name or State well number	Date	Sample start time	Sample type	Arsenite (H_3AsO_3, As[III], water, filtered, (µg-As/L)	Barium, water, filtered (µg/L)	Beryllium, water, filtered (µg/L)	Boron, water, filtered (µg/L)	Cadmium, water, filtered (µg/L)	Chromium, water, filtered (µg/L)	Cobalt, water, filtered (µg/L)	Copper, water, filtered (µg/L)
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	6/4/2007	1359	Equipment blank	<1.0	M	<0.06	<8	<0.04	<0.12	<0.04	0.71
300359095122902	LJ–60–63–510	6/26/2007	0859	Field blank	<1.0	M	<.06	<8	<.04	<.12	<.04	.60
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	8/4/2008	1059	Equipment blank	<.6	<.4	<.01	<6	<.04	<.12	<.02	<1.0
295228095262901	LJ–65–13–220	8/11/2008	0959	Field Blank	<.6	<.4	<.01	<6	<.04	<.12	<.02	<1.0

U.S. Geological Survey site number	Site name or State well number	Date	Sample start time	Sample type	Iron, water, filtered (µg/L)	Lead, water, filtered (µg/L)	Lithium, water, filtered (µg/L)	Manganese, water, filtered (µg/L)	Molybdenum, water, filtered (µg/L)	Nickel, water, filtered (µg/L)	Selenium, water, filtered (µg/L)	Silver, water, filtered (µg/L)
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	6/4/2007	1359	Equipment blank	<6	<0.12	<0.6	E0.2	<0.1	E0.05	<0.08	<0.1
300359095122902	LJ–60–63–510	6/26/2007	0859	Field blank	<6	<.12	<.6	<.2	<.1	.09	<.08	<.1
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	8/4/2008	1059	Equipment blank	<8	<.08	<1.0	<.2	<.2	<.20	<.04	<.1
295228095262901	LJ–65–13–220	8/11/2008	0959	Field blank	<8	<.08	<1.0	<.2	<.2	<.20	<.04	<.1

Table 4. Results of major ion, trace element, and radionuclide analyses from quality control samples, equipment blanks, and field blanks, collected in association with municipal supply wells sampled in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	Site name or State well number	Date	Sample start time	Sample type	Strontium, water, filtered (µg/L)	Thallium, water, filtered (µg/L)	Vanadium, water, filtered (µg/L)	Zinc, water, filtered (µg/L)	Dimethylarsinate ($(CH_3)_2HAsO_2$; DMA), water, filtered, recoverable (µg-As/L)	Monomethylarsonate ($(CH_3)HAsO_3^-$; MMA), water, filtered, recoverable (µg-As/L)	Alpha radioactivity, 30-day count, water, filtered, Th-230 curve (pCi/L)	Alpha radioactivity, 30-day count, 1-sigma CSU, water, filtered, Th-230 curve (pCi/L)
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	6/4/2007	1359	Equipment blank	<0.40	<0.04	<0.04	E0.39	<0.6	<1.2	--	--
300359095122902	LJ–60–63–510	6/26/2007	0859	Field blank	<.40	<.04	<.04	1.1	<.6	<1.2	--	--
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	8/4/2008	1059	Equipment blank	<.80	<.04	<.04	<1.8	<.6	<1.8	-0.02	0.14
295228095262901	LJ–65–13–220	8/11/2008	0959	Field blank	<.80	<.04	<.04	<1.8	<.6	<1.8	--	--

U.S. Geological Survey site number	Site name or State well number	Date	Sample start time	Sample type	Alpha radioactivity, 30-day count, ssL_c, water, filtered, Th-230 curve (pCi/L)	Alpha radioactivity, 30-day count, remark code	Alpha radioactivity, 72-hour count, water, filtered, Th-230 curve (pCi/L)	Alpha radioactivity, 72-hour count, 1-sigma CSU, water, filtered, Th-230 curve pCi/L	Alpha radioactivity, 72-hour count, ssL_c, water, filtered, Th-230 curve (pCi/L)	Alpha radioactivity, 72-hour count, remark code	Beta radioactivity, 30-day count, water, filtered, Cs-137 curve (pCi/L)	Beta radioactivity, 30-day count, 1-sigma CSU, water, filtered, Cs-137 curve (pCi/L)
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	6/4/2007	1359	Equipment blank	--	--	--	--	--	--	--	--
300359095122902	LJ–60–63–510	6/26/2007	0859	Field blank	--	--	--	--	--	--	--	--
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	8/4/2008	1059	Equipment blank	0.22	R	0.11	0.13	0.18	R	-0.2	0.65
295228095262901	LJ–65–13–220	8/11/2008	0959	Field blank	--	--	--	--	--	--	--	--

Table 4. Results of major ion, trace element, and radionuclide analyses from quality control samples, equipment blanks, and field blanks, collected in association with municipal supply wells sampled in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	Site name or State well number	Date	Sample start time	Sample type	Beta radioactivity, 30-day count, $\mathrm{ssL_C}$, water, filtered, Cs-137 curve (pCi/L)	Beta radioactivity, 30-day count, remark code	Beta radioactivity, 72-hour count, water, filtered, Cs-137 curve (pCi/L)	Beta radioactivity, 72-hour count, 1-sigma CSU, water, filtered, Cs-137 curve, pCi/L	Beta radioactivity, 72-hour count, $\mathrm{ssL_C}$, water, filtered, Cs-137 curve (pCi/L)	Beta radioactivity, 72-hour count, remark code	Radium-226, water, filtered, radon method (pCi/L)	Radium-226, 1-sigma CSU, water, filtered, radon method (pCi/L)
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	6/4/2007	1359	Equipment blank	--	--	--	--	--	--	0.017	0.011
300359095122902	LJ–60–63–510	6/26/2007	0859	Field blank	--	--	--	--	--	--	--	--
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	8/4/2008	1059	Equipment blank	1.0	R	0.1	0.30	0.48	R	.0223	.0097
295228095262901	LJ–65–13–220	8/11/2008	0959	Field blank	--	--	--	--	--	--	--	--

U.S. Geological Survey site number	Site name or State well number	Date	Sample start time	Sample type	Radium-226, $\mathrm{ssL_C}$, water, filtered, radon method (pCi/L)	Radium-226 remark code	Radium-228, water, filtered (pCi/L)	Radium-228, 1-sigma CSU, water, filtered (pCi/L)	Radium-228, $\mathrm{ssL_C}$, water, filtered (pCi/L)	Radium-228, remark code	Uranium (natural), water, filtered (µg/L)	Uranium (natural), LRL, water, filtered (µg/L)
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	6/4/2007	1359	Equipment blank	0.015	--	0.09	0.10	0.24	R	<0.04	0.04
300359095122902	LJ–60–63–510	6/26/2007	0859	Field blank	--	--	--	--	--	--	<.04	.04
301056095265000	USGS TWSC, Gulf Coast Program Office Laboratory, Shenandoah, Tex.	8/4/2008	1059	Equipment blank	.0130	--	.32	.15	.28	d	<.02	.02
295228095262901	LJ–65–13–220	8/11/2008	0959	Field blank	--	--	--	--	--	--	<.02	.02

Table 5. Relative percent differences (RPD) between sequential replicate and environmental samples analyzed for major ions, trace elements, and radionuclides and collected in association with municipal supply wells sampled in the Houston, Texas, area, 2007–08.

[RPDs are percentages; mg/L, milligrams per liter; $CaCO_3$, calcium carbonate; °C, degrees Celsius; µg-As/L, micrograms arsenic per liter; µg/L, micrograms per liter; Th, thorium; pCi/L, picocuries per liter; Cs, cesium; --, no data available]

	Major ions											
	Calcium, water, filtered (mg/L)	Magnesium, water, filtered (mg/L)	Potassium, water, filtered (mg/L)	Sodium, water, filtered (mg/L)	Alkalinity, water, filtered, inflection-point titration method (incremental titration method), field (mg/L as $CaCO_3$)	Bicarbonate, water, filtered, inflection-point titration method (incremental titration method), field (mg/L)	Bromide, water, filtered (mg/L)	Chloride, water, filtered (mg/L)	Fluoride, water, filtered (mg/L)	Silica, water, filtered (mg/L as SiO_2)	Sulfate, water, filtered (mg/L)	Residue on evaporation, dried at 180 °C, water, filtered (mg/L)
Number of pairs with detected values	4	4	4	4	4	4	3	3	3	3	2	4
Minimum RPD	.4	.3	0	0	0	0	0	0	0	0	0	.7
Average RPD	1.1	1.0	.3	.3	.8	.8	1.8	.3	.3	.5	.3	2.5
Maximum RPD	1.7	1.8	.7	.7	2.1	2.0	5.2	1.0	.5	1.3	.6	8.6

	Trace elements											
	Arsenate ($H_2AsO_4^-$, As[V]), water, filtered (µg-As/L)	Arsenic, water, filtered (µg/L)	Arsenite (H_3AsO_3, As[III]), water, filtered (µg-As/L)	Barium, water, filtered (µg/L)	Boron, water, filtered (µg/L)	Iron, water, filtered (µg/L)	Lithium, water, filtered (µg/L)	Manganese, water, filtered (µg/L)	Molybdenum, water, filtered (µg/L)	Nickel, water, filtered (µg/L)	Strontium, water, filtered (µg/L)	Vanadium, water, filtered (µg/L)
Number of pairs with detected values	2	4	3	4	4	3	4	4	4	3	4	3
Minimum RPD	2.4	0	0	0	0	0	.8	0	0	0	0	0
Average RPD	3.5	.7	.6	.6	2.7	1.9	4.6	.1	2.5	3.2	.9	9.6
Maximum RPD	4.7	2.5	1.8	1.2	6.8	3.7	8.2	.4	6.8	7.3	2.1	20

Table 5. Relative percent differences (RPD) between sequential replicate and environmental samples analyzed for major ions, trace elements, and radionuclides and collected in association with municipal supply wells sampled in the Houston, Texas, area, 2007–08—Continued.

	Radionuclides							
	Alpha radioactivity, 30-day count, water, filtered, Th-230 curve (pCi/L)	**Alpha radioactivity, 72-hour count, water, filtered, Th-230 curve (pCi/L)**	**Beta radioactivity, 30-day count, water, filtered, Cs-137 curve (pCi/L)**	**Beta radioactivity, 72-hour count, water, filtered, Cs-137 curve (pCi/L)**	**Carbon-13/ carbon-12 ratio, water, unfiltered (per mil)**	**Radium-226, water, filtered, radon method (pCi/L)**	**Radium-228, water, filtered (pCi/L)**	**Radon-222, water, unfiltered (pCi/L)**
Number of pairs with detected values	2	5	4	6	3	6	3	6
Number of pairs that overlap with +/- CSU	2	5	3	6	--	--	2	6
Minimum RPD	27	7.3	1.1	6.1	1.4	3.0	2.9	0
Average RPD	37	21	24	18	3.0	10	22	4.8
Maximum RPD	47	48	64	47	5.4	22	60	13

Table 6. Physicochemical properties and results of major ions and organic carbon analyses in water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08.

[nm, nanometers; NTRU, Nephelometric Turbidity Ratio Unit; mg/L, milligrams per liter; °C, degrees Celsius; E, estimated; --, no data available; <, less than; $CaCO_3$, calcium carbonate; U, analyzed for but not detected: M, presence verified but not quantified]

U.S. Geological Survey site number	State well number	Date	Time	Sample type	Oxidation reduction potential (ORP), reference electrode not specified (millivolts)	Turbidity, water, unfiltered, broad band light source (400–680 nm), detectors at multiple angles including 90 +/- 30 degrees, ratiometric correction (NTRU)	Barometric pressure (millimeters of mercury)	Dissolved oxygen (DO), water, unfiltered (mg/L)	pH, water, unfiltered, field (standard units)	Specific conductance, water, unfiltered (microsiemens per centimeter at 25 °C)	Temperature, air (°C)
Wells sampled in 2007											
300419095154301	TS–60–62–604	6/25/2007	1130	Environmental	-203	0.2	758	E0.2	8.0	688	27.0
300419095154301	TS–60–62–604	6/25/2007	1131	Sequential replicate	--	--	--	--	--	--	--
300258095145301	TS–60–63–404	6/25/2007	1430	Environmental	-115	.1	766	<.1	7.5	371	29.2
300359095122902	LJ–60–63–510	6/26/2007	0945	Environmental	-137	.1	759	<.1	7.5	325	--
300302095113301	LJ–60–63–511	6/26/2007	1145	Environmental	-146	.1	759	<.1	7.6	331	--
300355095093501	LJ–60–63–602	6/26/2007	1345	Environmental	92.8	.5	759	2.5	7.6	314	27.6
300225095144202	LJ–60–63–709	6/27/2007	0910	Environmental	-54.3	.1	759	<.1	7.5	400	31.0
300231095113701	LJ–60–63–508	6/27/2007	1120	Environmental	-151	.1	759	<.1	7.6	327	34.2
300334095113401	LJ–60–63–504	6/27/2007	1400	Environmental	-137	.1	759	<.1	7.6	331	34.5
300403095125402	LJ–60–63–502	6/28/2007	0900	Environmental	-146	.1	757	<.1	7.6	332	34.8
300426095123902	LJ–60–63–407	6/28/2007	1140	Environmental	-128	.1	757	<.1	7.6	331	34.7
300426095123902	LJ–60–63–407	6/28/2007	1141	Sequential replicate	--	--	--	--	--	--	--

Table 6. Physicochemical properties and results of major ions and organic carbon analyses in water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Time	Sample type	Oxidation reduction potential (ORP), reference electrode not specified (millivolts)	Turbidity, water, unfiltered, broad band light source (400–680 nm), detectors at multiple angles including 90 +/- 30 degrees, ratiometric correction (NTRU)	Barometric pressure (millimeters of mercury)	Dissolved oxygen (DO), water, unfiltered (mg/L)	pH, water, unfiltered, field (standard units)	Specific conductance, water, unfiltered (microsiemens per centimeter at 25 °C)	Temperature, air (°C)
300408095115201	LJ–60–63–503	7/9/2007	0920	Environmental	-156	0.1	756	<0.1	7.7	341	31.0
300446095121901	TS–60–63–507	7/9/2007	1200	Environmental	-142	.1	756	<.1	7.7	349	34.1
300343095090301	LJ–60–63–604	7/10/2007	0925	Environmental	167	.1	757	E4.2	7.7	324	30.0
300248095105301	LJ–60–63–505	7/10/2007	1120	Environmental	-154	.1	757	<.1	7.6	320	34.8
Wells sampled in 2008											
294113095361701	LJ–65–20–421	8/6/2008	1055	Environmental	105	.2	760	.4	7.9	571	--
294113095361702	LJ–65–20–422	8/6/2008	1330	Environmental	112	.1	760	3.8	7.5	521	39.0
294131095360701	LJ–65–20–407	8/6/2008	1540	Environmental	154	1.9	760	3.0	7.3	536	40.0
294147095344303	LJ–65–20–513	8/7/2008	0940	Environmental	244	.1	761	3.1	7.4	523	33.5
294144095351002	LJ–65–20–409	8/7/2008	1205	Environmental	236	.1	761	2.4	7.3	552	37.5
294149095363002	LJ–65–20–408	8/7/2008	1410	Environmental	179	.1	759	1.3	7.5	523	--
295228095262901	LJ–65–13–220	8/11/2008	1105	Environmental	167	.2	756	1.8	7.4	533	33.5
295228095263101	LJ–65–13–222	8/11/2008	1350	Environmental	-208	.1	755	<.1	8.1	830	42.5
295228095263101	LJ–65–13–222	8/11/2008	1351	Sequential replicate	--	--	--	<.1	--	--	--

Table 6. Physicochemical properties and results of major ions and organic carbon analyses in water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Time	Sample type	Oxidation reduction potential (ORP), reference electrode not specified (millivolts)	Turbidity, water, unfiltered, broad band light source (400–680 nm), detectors at multiple angles including 90 +/- 30 degrees, ratiometric correction (NTRU)	Barometric pressure (millimeters of mercury)	Dissolved oxygen (DO), water, unfiltered (mg/L)	pH, water, unfiltered, field (standard units)	Specific conductance, water, unfiltered (microsiemens per centimeter at 25 °C)	Temperature, air (°C)
295207095262102	LJ–65–13–221	8/12/2008	1035	Environmental	171	0.1	755	4.3	7.2	519	33.9
295306095270502	LJ–65–05–813	8/12/2008	1350	Environmental	137	.4	754	4.5	7.4	531	34.9
295150095254601	LJ–65–13–214	8/13/2008	1030	Environmental	222	.1	755	.5	7.4	515	33.0
295150095254601	LJ–65–13–214	8/13/2008	1031	Sequential replicate	--	--	--	--	--	--	--
295251095264502	LJ–65–05–814	8/13/2008	1350	Environmental	28.9	.1	755	1.0	7.4	550	39.5
295203095261401	LJ–65–13–224	8/14/2008	1030	Environmental	-212	.1	756	<.1	7.9	856	31.0
295203095261401	LJ–65–13–224	8/14/2008	1031	Sequential replicate	--	--	--	--	--	--	--
295204095261301	LJ–65–13–225	8/14/2008	1305	Environmental	-147	.1	756	<.1	7.5	540	41.0

Table 6. Physicochemical properties and results of major ions and organic carbon analyses in water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Time	Sample type	Temperature, water (°C)	Calcium, water, filtered (mg/L)	Magnesium, water, filtered (mg/L)	Potassium, water, filtered (mg/L)	Sodium, water, filtered (mg/L)	Alkalinity, water, filtered, inflection-point titration method (incremental titration method), field (mg/L as $CaCO_3$)	Bicarbonate, water, filtered, inflection-point titration method (incremental titration method), field (mg/L)
					Wells sampled in 2007						
300419095154301	TS–60–62–604	6/25/2007	1130	Environmental	28.1	11.8	2.67	1.82	136	222	267
300419095154301	TS–60–62–604	6/25/2007	1131	Sequential replicate	--	11.5	2.60	1.81	136	215	259
300258095145301	TS–60–63–404	6/25/2007	1430	Environmental	25.9	41.1	5.48	2.17	26.6	143	174
300359095122902	LJ–60–63–510	6/26/2007	0945	Environmental	25.6	45.4	3.55	2.26	14.2	131	160
300302095113301	LJ–60–63–511	6/26/2007	1145	Environmental	25.7	38.2	3.96	2.19	22.1	136	166
300355095093501	LJ–60–63–602	6/26/2007	1345	Environmental	25.1	39.0	3.36	2.67	19.8	131	160
300225095144202	LJ–60–63–709	6/27/2007	0910	Environmental	25.9	40.5	5.71	2.54	31.3	167	203
300231095113701	LJ–60–63–508	6/27/2007	1120	Environmental	25.2	39.4	4.07	2.29	19.8	131	160
300334095113401	LJ–60–63–504	6/27/2007	1400	Environmental	25.6	38.0	3.85	2.36	23.1	131	160
300403095125402	LJ–60–63–502	6/28/2007	0900	Environmental	25.1	46.4	3.64	2.23	14.5	136	166
300426095123902	LJ–60–63–407	6/28/2007	1140	Environmental	25.7	41.8	3.31	2.40	18.3	131	160
300426095123902	LJ–60–63–407	6/28/2007	1141	Sequential replicate	--	42.7	3.38	2.40	18.5	131	160

Table 6. Physicochemical properties and results of major ions and organic carbon analyses in water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Time	Sample type	Temperature, water (°C)	Calcium, water, filtered (mg/L)	Magnesium, water, filtered (mg/L)	Potassium, water, filtered (mg/L)	Sodium, water, filtered (mg/L)	Alkalinity, water, filtered, inflection-point titration method (incremental titration method), field (mg/L as $CaCO_3$)	Bicarbonate, water, filtered, inflection-point titration method (incremental titration method), field (mg/L)
300408095115201	LJ–60–63–503	7/9/2007	0920	Environmental	25.7	35.8	3.43	2.35	25.7	136	166
300446095121901	TS–60–63–507	7/9/2007	1200	Environmental	25.5	37.8	3.60	2.37	27.3	142	173
300343095090301	LJ–60–63–604	7/10/2007	0925	Environmental	25.1	36.7	3.10	2.65	26.0	126	154
300248095105301	LJ–60–63–505	7/10/2007	1120	Environmental	25.5	38.0	4.01	2.40	22.1	126	154
					Wells sampled in 2008						
294113095361701	LJ–65–20–421	8/6/2008	1055	Environmental	28.9	16.1	4.41	1.88	103	207	253
294113095361702	LJ–65–20–422	8/6/2008	1330	Environmental	25.9	52.5	8.90	2.16	38.5	182	222
294131095360701	LJ–65–20–407	8/6/2008	1540	Environmental	25.3	59.9	9.77	1.89	34.3	192	234
294147095344303	LJ–65–20–513	8/7/2008	0940	Environmental	25.4	52.2	9.69	2.00	40.4	187	228
294144095351002	LJ–65–20–409	8/7/2008	1205	Environmental	25.7	61.8	10.5	1.83	34.3	207	253
294149095363002	LJ–65–20–408	8/7/2008	1410	Environmental	26.8	40.4	7.76	2.08	53.2	187	228
295228095262901	LJ–65–13–220	8/11/2008	1105	Environmental	25.0	49.5	8.78	2.59	38.8	177	216
295228095263101	LJ–65–13–222	8/11/2008	1350	Environmental	29.9	8.50	2.09	1.91	178	324	394
295228095263101	LJ–65–13–222	8/11/2008	1351	Sequential replicate	--	8.55	2.10	1.89	179	329	401

Table 6. Physicochemical properties and results of major ions and organic carbon analyses in water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Time	Sample type	Temperature, water (°C)	Calcium, water, filtered (mg/L)	Magnesium, water, filtered (mg/L)	Potassium, water, filtered (mg/L)	Sodium, water, filtered (mg/L)	Alkalinity, water, filtered, inflection-point titration method (incremental titration method), field (mg/L as $CaCO_3$)	Bicarbonate, water, filtered, inflection-point titration method (incremental titration method), field (mg/L)
295207095262102	LJ–65–13–221	8/12/2008	1035	Environmental	23.5	66.4	6.57	1.47	27.6	187	228
295306095270502	LJ–65–05–813	8/12/2008	1350	Environmental	25.5	49.8	8.03	2.53	44.0	167	203
295150095254601	LJ–65–13–214	8/13/2008	1030	Environmental	25.2	47.4	8.84	2.48	46.0	172	210
295150095254601	LJ–65–13–214	8/13/2008	1031	Sequential replicate	--	46.7	8.79	2.49	46.0	172	210
295251095264502	LJ–65–05–814	8/13/2008	1350	Environmental	26.4	47.2	8.09	2.57	51.0	167	203
295203095261401	LJ–65–13–224	8/14/2008	1030	Environmental	29.7	8.23	1.99	1.80	182	313	382
295203095261401	LJ–65–13–224	8/14/2008	1031	Sequential replicate	--	--	--	--	--	--	--
295204095261301	LJ–65–13–225	8/14/2008	1305	Environmental	26.7	32.9	7.68	2.47	65.6	182	222

Table 6. Physicochemical properties and results of major ions and organic carbon analyses in water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Time	Sample type	Carbonate, water, filtered, inflection-point titration method (incremental titration method), field (mg/L)	Bromide, water, filtered (mg/L)	Chloride, water, filtered (mg/L)	Fluoride, water, filtered (mg/L)	Silica, water, filtered, (mg/L as SiO_2)	Sulfate, water, filtered (mg/L)	Hydrogen sulfide, water, unfiltered (mg/L)[1]
Wells sampled in 2007											
300419095154301	TS–60–62–604	6/25/2007	1130	Environmental	2	0.32	83.3	1.34	15.7	<0.18	U
300419095154301	TS–60–62–604	6/25/2007	1131	Sequential replicate	2	.31	83.0	1.35	15.4	<.18	--
300258095145301	TS–60–63–404	6/25/2007	1430	Environmental	--	.07	20.6	.14	23.1	11.2	M
300359095122902	LJ–60–63–510	6/26/2007	0945	Environmental	--	.07	15.6	.12	23.8	11.7	M
300302095113301	LJ–60–63–511	6/26/2007	1145	Environmental	--	.07	18.4	.18	22.2	9.36	M
300355095093501	LJ–60–63–602	6/26/2007	1345	Environmental	--	.08	19.2	.15	24.1	5.46	U
300225095144202	LJ–60–63–709	6/27/2007	0910	Environmental	--	.09	25.7	.19	26.7	10.6	M
300231095113701	LJ–60–63–508	6/27/2007	1120	Environmental	--	.07	15.3	.16	23.6	10.4	M
300334095113401	LJ–60–63–504	6/27/2007	1400	Environmental	--	.08	19.1	.24	23.1	7.53	M
300403095125402	LJ–60–63–502	6/28/2007	0900	Environmental	--	.06	15.6	.17	26.3	11.5	M
300426095123902	LJ–60–63–407	6/28/2007	1140	Environmental	--	.07	16.6	.14	25.9	10.2	M
300426095123902	LJ–60–63–407	6/28/2007	1141	Sequential replicate	--	.07	16.6	.14	25.8	10.2	--

Table 6. Physicochemical properties and results of major ions and organic carbon analyses in water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Time	Sample type	Carbonate, water, filtered, inflection-point titration method (incremental titration method), field (mg/L)	Bromide, water, filtered (mg/L)	Chloride, water, filtered (mg/L)	Fluoride, water, filtered (mg/L)	Silica, water, filtered, (mg/L as SiO_2)	Sulfate, water, filtered (mg/L)	Hydrogen sulfide, water, unfiltered (mg/L)[1]
300408095115201	LJ–60–63–503	7/9/2007	0920	Environmental	--	0.09	21.8	.15	22.7	5.57	M
300446095121901	TS–60–63–507	7/9/2007	1200	Environmental	--	.10	23.6	.23	22.4	6.94	M
300343095090301	LJ–60–63–604	7/10/2007	0925	Environmental	--	.08	21.7	.20	24.8	3.19	U
300248095105301	LJ–60–63–505	7/10/2007	1120	Environmental	--	.07	17.7	.16	22.0	7.26	M
Wells sampled in 2008											
294113095361701	LJ–65–20–421	8/6/2008	1055	Environmental	--	0.13	43.7	0.65	16.2	17.2	M
294113095361702	LJ–65–20–422	8/6/2008	1330	Environmental	--	.17	48.6	.24	26.3	12.1	U
294131095360701	LJ–65–20–407	8/6/2008	1540	Environmental	--	.15	46.1	.22	25.9	9.18	M
294147095344303	LJ–65–20–513	8/7/2008	0940	Environmental	--	.15	42.6	.23	26.8	10.6	U
294144095351002	LJ–65–20–409	8/7/2008	1205	Environmental	--	.15	44.2	.21	26.3	8.40	U
294149095363002	LJ–65–20–408	8/7/2008	1410	Environmental	--	.14	42.3	.30	21.8	13.0	U
295228095262901	LJ–65–13–220	8/11/2008	1105	Environmental	--	.17	53.5	.20	24.1	9.30	U
295228095263101	LJ–65–13–222	8/11/2008	1350	Environmental	--	.25	83.1	1.32	15.1	E.17	M
295228095263101	LJ–65–13–222	8/11/2008	1351	Sequential replicate	--	.27	84.4	1.33	15.1	.21	--

Table 6. Physicochemical properties and results of major ions and organic carbon analyses in water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Time	Sample type	Carbonate, water, filtered, inflection-point titration method (incremental titration method), field (mg/L)	Bromide, water, filtered (mg/L)	Chloride, water, filtered (mg/L)	Fluoride, water, filtered (mg/L)	Silica, water, filtered, (mg/L as SiO_2)	Sulfate, water, filtered (mg/L)	Hydrogen sulfide, water, unfiltered (mg/L)[1]
295207095262102	LJ–65–13–221	8/12/2008	1035	Environmental	--	0.12	47.2	E0.11	25.9	4.82	U
295306095270502	LJ–65–05–813	8/12/2008	1350	Environmental	--	.19	56.6	.19	23.6	10.1	U
295150095254601	LJ–65–13–214	8/13/2008	1030	Environmental	--	.16	48.1	.21	23.4	11.6	U
295150095254601	LJ–65–13–214	8/13/2008	1031	Sequential replicate	--	.16	48.1	.21	23.5	11.5	--
295251095264502	LJ–65–05–814	8/13/2008	1350	Environmental	--	.18	62.6	.24	22.6	10.3	U
295203095261401	LJ–65–13–224	8/14/2008	1030	Environmental	--	.27	85.4	1.22	14.2	.81	M
295203095261401	LJ–65–13–224	8/14/2008	1031	Sequential replicate	--	--	--	--	--	--	--
295204095261301	LJ–65–13–225	8/14/2008	1305	Environmental	--	.17	50.5	.31	16.8	10.1	M

Table 6. Physicochemical properties and results of major ions and organic carbon analyses in water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Time	Sample type	Sulfide, water, unfiltered, field (mg/L)	Residue on evaporation, dried at 180 °C, water, filtered (mg/L)	Organic carbon (DOC), water, filtered (mg/L)	Chemical oxygen demand (COD), high level, water, unfiltered (mg/L)
					Wells sampled in 2007			
300419095154301	TS–60–62–604	6/25/2007	1130	Environmental	<0.005	379	E0.3	<10
300419095154301	TS–60–62–604	6/25/2007	1131	Sequential replicate	--	430	E.3	<10
300258095145301	TS–60–63–404	6/25/2007	1430	Environmental	<.005	216	<.4	<10
300359095122902	LJ–60–63–510	6/26/2007	0945	Environmental	.014	190	<.4	<10
300302095113301	LJ–60–63–511	6/26/2007	1145	Environmental	<.005	194	<.4	<10
300355095093501	LJ–60–63–602	6/26/2007	1345	Environmental	<.005	185	<.4	<10
300225095144202	LJ–60–63–709	6/27/2007	0910	Environmental	.008	230	<.4	<10
300231095113701	LJ–60–63–508	6/27/2007	1120	Environmental	.006	200	<.4	<10
300334095113401	LJ–60–63–504	6/27/2007	1400	Environmental	<.005	196	<.4	<10
300403095125402	LJ–60–63–502	6/28/2007	0900	Environmental	.008	201	E.2	<10
300426095123902	LJ–60–63–407	6/28/2007	1140	Environmental	<.005	198	<.4	<10
300426095123902	LJ–60–63–407	6/28/2007	1141	Sequential replicate	--	200	<.4	<10

Table 6. Physicochemical properties and results of major ions and organic carbon analyses in water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Time	Sample type	Sulfide, water, unfiltered, field (mg/L)	Residue on evaporation, dried at 180 °C, water, filtered (mg/L)	Organic carbon (DOC), water, filtered (mg/L)	Chemical oxygen demand (COD), high level, water, unfiltered (mg/L)
300408095115201	LJ–60–63–503	7/9/2007	0920	Environmental	0.013	190	<0.4	<10
300446095121901	TS–60–63–507	7/9/2007	1200	Environmental	.009	208	E.3	<10
300343095090301	LJ–60–63–604	7/10/2007	0925	Environmental	--	175	<.4	<10
300248095105301	LJ–60–63–505	7/10/2007	1120	Environmental	.006	182	E.2	<10
					Wells sampled in 2008			
294113095361701	LJ–65–20–421	8/6/2008	1055	Environmental	<.20	321	E.3	<10
294113095361702	LJ–65–20–422	8/6/2008	1330	Environmental	--	307	<.4	<10
294131095360701	LJ–65–20–407	8/6/2008	1540	Environmental	--	307	<.4	<10
294147095344303	LJ–65–20–513	8/7/2008	0940	Environmental	--	306	<.4	<10
294144095351002	LJ–65–20–409	8/7/2008	1205	Environmental	--	313	<.4	<10
294149095363002	LJ–65–20–408	8/7/2008	1410	Environmental	--	303	<0.4	<10
295228095262901	LJ–65–13–220	8/11/2008	1105	Environmental	--	301	E.2	<10
295228095263101	LJ–65–13–222	8/11/2008	1350	Environmental	<.20	496	E.4	<10
295228095263101	LJ–65–13–222	8/11/2008	1351	Sequential replicate	<.20	505	.4	<10

Table 6. Physicochemical properties and results of major ions and organic carbon analyses in water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Time	Sample type	Sulfide, water, unfiltered, field (mg/L)	Residue on evaporation, dried at 180 °C, water, filtered (mg/L)	Organic carbon (DOC), water, filtered (mg/L)	Chemical oxygen demand (COD), high level, water, unfiltered (mg/L)
295207095262102	LJ–65–13–221	8/12/2008	1035	Environmental	--	311	E0.3	<10
295306095270502	LJ–65–05–813	8/12/2008	1350	Environmental	--	307	E.2	<10
295150095254601	LJ–65–13–214	8/13/2008	1030	Environmental	<.20	289	<.4	<10
295150095254601	LJ–65–13–214	8/13/2008	1031	Sequential replicate	<.20	297	<.4	<10
295251095264502	LJ–65–05–814	8/13/2008	1350	Environmental	<.20	324	<0.4	<10
295203095261401	LJ–65–13–224	8/14/2008	1030	Environmental	<.20	486	E.4	<10
295203095261401	LJ–65–13–224	8/14/2008	1031	Sequential replicate	<.20	--	--	--
295204095261301	LJ–65–13–225	8/14/2008	1305	Environmental	<.20	298	<.4	<10

[1] Serendipitous sniff test, unacidified sample.

Table 7. Results of arsenic and other trace elements analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08.

[µg/L, micrograms per liter; µg-As/L, micrograms arsenic per liter; <, less than; E, estimated; --, no data available; M, presence verified but not quantified]

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Aluminum, water, filtered (µg/L)	Antimony, water, filtered (µg/L)	Arsenate ($H_2AsO_4^-$, As[V]), water, filtered (µg-As/L)	Arsenic, water, filtered (µg/L)	Arsenite (H_3AsO_3, As[III]), water, filtered (µg-As/L)	Barium, water, filtered (µg/L)	Beryllium, water, filtered (µg/L)	Boron, water, filtered (µg/L)	Cadmium, water, filtered (µg/L)
Wells sampled in 2007													
300419095154301	TS–60–62–604	6/25/2007	1130	Environmental	<1.6	<0.06	1.4	15.3	14.9	146	<0.06	548	0.04
300419095154301	TS–60–62–604	6/25/2007	1131	Sequential replicate	<1.6	E.03	1.5	15.2	15.3	147	<.06	548	E.03
300258095145301	TS–60–63–404	6/25/2007	1430	Environmental	E1.1	<.06	<.8	1.4	1.2	275	<.06	34	<.04
300359095122902	LJ–60–63–510	6/26/2007	0945	Environmental	<1.6	<.06	<.8	1.5	1.6	267	<.06	20	<.04
300302095113301	LJ–60–63–511	6/26/2007	1145	Environmental	<1.6	<.06	<.8	2.9	2.9	296	<.06	38	<.04
300355095093501	LJ–60–63–602	6/26/2007	1345	Environmental	<1.6	E.03	1.3	1.7	<1.0	337	<.06	27	<.04
300225095144202	LJ–60–63–709	6/27/2007	0910	Environmental	<1.6	<.06	<.8	1.3	1.1	286	<.06	50	<.04
300231095113701	LJ–60–63–508	6/27/2007	1120	Environmental	<1.6	<.06	<.8	2.6	2.5	278	<.06	38	<.04
300334095113401	LJ–60–63–504	6/27/2007	1400	Environmental	<1.6	<.06	.9	3.8	3.0	305	<.06	57	<.04
300403095125402	LJ–60–63–502	6/28/2007	0900	Environmental	3.0	<.06	<.8	1.3	1.5	262	<.06	23	<.04
300426095123902	LJ–60–63–407	6/28/2007	1140	Environmental	<1.6	<.06	<.8	.80	E1.0	293	<.06	26	<.04
300426095123902	LJ–60–63–407	6/28/2007	1141	Sequential replicate	<1.6	<.06	--	.77	--	290	<.06	27	<.04
300408095115201	LJ–60–63–503	7/9/2007	0920	Environmental	<1.6	<.06	<.8	.58	E.8	324	<.06	38	<.04
300446095121901	TS–60–63–507	7/9/2007	1200	Environmental	1.7	<.06	<.8	1.5	2.1	325	<.06	46	<.04
300343095090301	LJ–60–63–604	7/10/2007	0925	Environmental	<1.6	E.03	1.7	1.8	<1.0	261	<.06	44	<.04
300248095105301	LJ–60–63–505	7/10/2007	1120	Environmental	3	<.06	<.8	1.6	2.0	335	<.06	31	<.04
300248095105301	LJ–60–63–505	7/10/2007	1121	Sequential replicate	--	--	<.8	--	2.0	--	--	--	--

Table 7. Results of arsenic and other trace elements analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Aluminum, water, filtered (µg/L)	Antimony, water, filtered (µg/L)	Arsenate ($H_2AsO_4^-$, As[V]), water, filtered (µg-As/L)	Arsenic, water, filtered (µg/L)	Arsenite (H_3AsO_3, As[III]), water, filtered (µg-As/L)	Barium, water, filtered (µg/L)	Beryllium, water, filtered (µg/L)	Boron, water, filtered (µg/L)	Cadmium, water, filtered (µg/L)
Wells sampled in 2008													
294113095361701	LJ–65–20–421	8/6/2008	1055	Environmental	E1.5	<0.14	<0.8	4.8	4.2	218	<0.01	155	<0.04
294113095361702	LJ–65–20–422	8/6/2008	1330	Environmental	<1.6	<.14	2.5	2.7	<.6	235	<.01	49	<.04
294131095360701	LJ–65–20–407	8/6/2008	1540	Environmental	<1.6	<.14	2.2	2.3	<.6	246	<.01	48	<.04
294147095344303	LJ–65–20–513	8/7/2008	0940	Environmental	<1.6	<.14	3.3	3.4	<.6	228	<.01	46	<.04
294144095351002	LJ–65–20–409	8/7/2008	1205	Environmental	<1.6	<.14	2.4	2.5	<.6	277	<.01	46	<.04
294149095363002	LJ–65–20–408	8/7/2008	1410	Environmental	E.9	<.14	2.4	2.5	<.6	234	<.01	67	<.04
295228095262901	LJ–65–13–220	8/11/2008	1105	Environmental	<1.6	<.14	3.1	3.4	<.6	288	<.01	47	<.04
295228095263101	LJ–65–13–222	8/11/2008	1350	Environmental	1.6	<.14	E.4	10.1	9.3	110	M	465	<.04
295228095263101	LJ–65–13–222	8/11/2008	1351	Sequential replicate	E1.5	<.14	--	10.1	--	112	<.01	419	<.04
295207095262102	LJ–65–13–221	8/12/2008	1035	Environmental	E.9	<.14	.8	1.0	<.6	241	E.01	38	<.04
295306095270502	LJ–65–05–813	8/12/2008	1350	Environmental	<1.6	<.14	2.2	2.5	<.6	312	<.01	44	<.04
295150095254601	LJ–65–13–214	8/13/2008	1030	Environmental	<1.6	<.14	2.7	3.1	<.6	232	<.01	46	<.04
295150095254601	LJ–65–13–214	8/13/2008	1031	Sequential replicate	<1.6	<.14	2.8	3.1	<.6	232	<.01	47	<.04
295251095264502	LJ–65–05–814	8/13/2008	1350	Environmental	<1.6	<.14	2.3	3.0	E.3	294	<.01	64	<.04
295203095261401	LJ–65–13–224	8/14/2008	1030	Environmental	2.6	<.14	E.5	7.8	7.0	125	M	407	<.04
295203095261401	LJ–65–13–224	8/14/2008	1031	Sequential replicate	--	--	E.4	--	7.0	--	--	--	--
295204095261301	LJ–65–13–225	8/14/2008	1305	Environmental	<1.6	<.14	<.8	1.6	1.2	408	<.01	68	<.04

Table 7. Results of arsenic and other trace elements analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Chromium, water, filtered (µg/L)	Cobalt, water, filtered (µg/L)	Copper, water, filtered (µg/L)	Iron, water, filtered (µg/L)	Lead, water, filtered (µg/L)	Lithium, water, filtered (µg/L)	Manganese, water, filtered (µg/L)	Molybdenum, water, filtered (µg/L)	Nickel, water, filtered (µg/L)
Wells sampled in 2007													
300419095154301	TS–60–62–604	6/25/2007	1130	Environmental	<0.12	<0.04	<0.40	165	<0.12	17.7	7.1	18.1	<0.06
300419095154301	TS–60–62–604	6/25/2007	1131	Sequential replicate	<.12	<.04	<.40	156	<.12	17.5	7.1	18.1	<.06
300258095145301	TS–60–63–404	6/25/2007	1430	Environmental	<.12	.07	<.40	265	<.12	8.3	109	3.9	.39
300359095122902	LJ–60–63–510	6/26/2007	0945	Environmental	<.12	<.04	<.40	175	<.12	5.0	79.4	1.7	.11
300302095113301	LJ–60–63–511	6/26/2007	1145	Environmental	<.12	<.04	<.40	132	<.12	6.6	65.7	2.5	.07
300355095093501	LJ–60–63–602	6/26/2007	1345	Environmental	.78	<.04	E.35	E4	.61	7.8	12.0	1.9	.13
300225095144202	LJ–60–63–709	6/27/2007	0910	Environmental	<.12	<.04	E.29	29	.13	12.6	3.4	4.7	.16
300231095113701	LJ–60–63–508	6/27/2007	1120	Environmental	<.12	<.04	<.40	144	E.11	8.3	77.5	1.8	.08
300334095113401	LJ–60–63–504	6/27/2007	1400	Environmental	<.12	<.04	.54	111	E.07	8.9	55.5	2.3	.09
300403095125402	LJ–60–63–502	6/28/2007	0900	Environmental	<.12	<.04	E.26	230	<.12	6.2	84.8	2.7	.19
300426095123902	LJ–60–63–407	6/28/2007	1140	Environmental	<.12	<.04	<.40	107	<.12	6.7	33.3	2.1	.06
300426095123902	LJ–60–63–407	6/28/2007	1141	Sequential replicate	<.12	<.04	<.40	104	<.12	7.5	33.1	2.0	.06
300408095115201	LJ–60–63–503	7/9/2007	0920	Environmental	<.12	<.04	E.30	148	<.12	5.9	16.3	1.9	.15
300446095121901	TS–60–63–507	7/9/2007	1200	Environmental	<.12	<.04	<.40	69	<.12	6.5	12.8	3.6	<.06
300343095090301	LJ–60–63–604	7/10/2007	0925	Environmental	1.2	<.04	1.3	<6	.38	6.0	<.2	3.5	.09
300248095105301	LJ–60–63–505	7/10/2007	1120	Environmental	<.12	<.04	E.36	122	E.07	7.0	34.4	1.4	.06
300248095105301	LJ–60–63–505	7/10/2007	1121	Sequential replicate	--	--	--	--	--	--	--	--	--

Table 7. Results of arsenic and other trace elements analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Chromium, water, filtered (µg/L)	Cobalt, water, filtered (µg/L)	Copper, water, filtered (µg/L)	Iron, water, filtered (µg/L)	Lead, water, filtered (µg/L)	Lithium, water, filtered (µg/L)	Man-ganese, water, filtered (µg/L)	Molybde-num, water, filtered (µg/L)	Nickel, water, filtered (µg/L)
Wells sampled in 2008													
294113095361701	LJ–65–20–421	8/6/2008	1055	Environmental	<0.12	<0.02	<1.0	32	0.09	21.3	8.9	7.3	E0.11
294113095361702	LJ–65–20–422	8/6/2008	1330	Environmental	2.0	.03	1.4	<8	.59	13.5	E.2	1.1	.34
294131095360701	LJ–65–20–407	8/6/2008	1540	Environmental	2.2	.03	<1.0	<8	.12	12.2	0.3	0.7	.39
294147095344303	LJ–65–20–513	8/7/2008	0940	Environmental	3.0	.02	1.3	<8	.09	12.2	0.4	0.9	.38
294144095351002	LJ–65–20–409	8/7/2008	1205	Environmental	1.6	.03	2.1	<8	.79	12.2	E.1	0.5	.47
294149095363002	LJ–65–20–408	8/7/2008	1410	Environmental	1.0	.02	3.3	E6	1.05	9.2	1.9	2.5	.51
295228095262901	LJ–65–13–220	8/11/2008	1105	Environmental	.24	E.02	2.1	8	.58	17.3	1.2	1.1	.61
295228095263101	LJ–65–13–222	8/11/2008	1350	Environmental	E.11	<.02	<1.0	77	<.08	23.8	5.9	5.7	.70
295228095263101	LJ–65–13–222	8/11/2008	1351	Sequential replicate	<.12	<.02	<1.0	77	<.08	21.0	5.9	6.3	.78
295207095262102	LJ–65–13–221	8/12/2008	1035	Environmental	1.5	.02	3.1	<8	.49	7.2	1.6	E.1	.34
295306095270502	LJ–65–05–813	8/12/2008	1350	Environmental	.67	.03	1.6	E8	.31	14.8	1.1	1.4	.27
295150095254601	LJ–65–13–214	8/13/2008	1030	Environmental	.22	.04	2.6	<8	.38	16.8	1.0	4.1	.31
295150095254601	LJ–65–13–214	8/13/2008	1031	Sequential replicate	.24	.04	3.0	<8	.40	17.3	1.0	4.1	.32
295251095264502	LJ–65–05–814	8/13/2008	1350	Environmental	.32	.02	<1.0	31	.74	17.2	2.9	2.2	.56
295203095261401	LJ–65–13–224	8/14/2008	1030	Environmental	<.12	<.02	<1.0	112	<.08	23.4	10.3	8.0	.27
295203095261401	LJ–65–13–224	8/14/2008	1031	Sequential replicate	--	--	--	--	--	--	--	--	--
295204095261301	LJ–65–13–225	8/14/2008	1305	Environmental	<.12	E.01	<1.0	131	.11	17.8	8.1	2.9	E.16

Table 7. Results of arsenic and other trace elements analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Selenium, water, filtered (µg/L)	Silver, water, filtered (µg/L)	Strontium, water, filtered (µg/L)	Thallium, water, filtered (µg/L)	Vanadium, water, filtered (µg/L)	Zinc, water, filtered (µg/L)	Dimethy-larsinate ((CH$_3$)$_2$HAsO$_2$, DMA), water, filtered, recoverable (µg-As/L)	Monomethyl-arsonate ((CH$_3$) HAsO$_3^-$, MMA), water, filtered, recoverable (µg-As/L)
					Wells sampled in 2007							
300419095154301	TS–60–62–604	6/25/2007	1130	Environmental	<0.08	<0.1	202	<0.04	0.08	1.1	E0.3	<1.2
300419095154301	TS–60–62–604	6/25/2007	1131	Sequential replicate	<.08	<.1	206	<.04	.07	1.9	E.4	<1.2
300258095145301	TS–60–63–404	6/25/2007	1430	Environmental	<.08	<.1	372	<.04	.06	3.4	<.6	<1.2
300359095122902	LJ–60–63–510	6/26/2007	0945	Environmental	<.08	<.1	241	<.04	E.02	.69	<.6	<1.2
300302095113301	LJ–60–63–511	6/26/2007	1145	Environmental	<.08	<.1	294	<.04	.11	.95	<.6	<1.2
300355095093501	LJ–60–63–602	6/26/2007	1345	Environmental	.74	<.1	277	<.04	1.7	E.56	<.6	<1.2
300225095144202	LJ–60–63–709	6/27/2007	0910	Environmental	<.08	<.1	435	<.04	2.6	2.6	<.6	<1.2
300231095113701	LJ–60–63–508	6/27/2007	1120	Environmental	<.08	<.1	317	<.04	.10	.65	<.6	<1.2
300334095113401	LJ–60–63–504	6/27/2007	1400	Environmental	<.08	<.1	320	<.04	E.02	1.5	<.6	<1.2
300403095125402	LJ–60–63–502	6/28/2007	0900	Environmental	<.08	<.1	241	<.04	.04	3.3	<.6	<1.2
300426095123902	LJ–60–63–407	6/28/2007	1140	Environmental	<.08	<.1	263	<.04	E.03	<.60	<.6	<1.2
300426095123902	LJ–60–63–407	6/28/2007	1141	Sequential replicate	<.08	<.1	263	<.04	E.03	<.60	--	--
300408095115201	LJ–60–63–503	7/9/2007	0920	Environmental	<.08	<.1	252	<.04	E.03	E.48	<.6	<1.2
300446095121901	TS–60–63–507	7/9/2007	1200	Environmental	<.08	<.1	239	<.04	<.04	<.60	<.6	<1.2
300343095090301	LJ–60–63–604	7/10/2007	0925	Environmental	1.0	<.1	233	<.04	2.0	E.49	<.6	<1.2
300248095105301	LJ–60–63–505	7/10/2007	1120	Environmental	<.08	<.1	271	<.04	<.04	E.34	<.6	<1.2
300248095105301	LJ–60–63–505	7/10/2007	1121	Sequential replicate	--	--	--	--	--	--	<.6	<1.2

Table 7. Results of arsenic and other trace elements analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Selenium, water, filtered (µg/L)	Silver, water, filtered (µg/L)	Strontium, water, filtered (µg/L)	Thallium, water, filtered (µg/L)	Vanadium, water, filtered (µg/L)	Zinc, water, filtered (µg/L)	Dimethylarsinate ($(CH_3)_2HAsO_2$, DMA), water, filtered, recoverable (µg-As/L)	Monomethylarsonate ($(CH_3)HAsO_3^-$, MMA), water, filtered, recoverable (µg-As/L)
					Wells sampled in 2008							
294113095361701	LJ–65–20–421	8/6/2008	1055	Environmental	0.04	0.1	407	<0.04	0.08	<1.8	<0.6	<1.8
294113095361702	LJ–65–20–422	8/6/2008	1330	Environmental	15.7	<.1	546	<.04	10.8	3.4	<.6	<1.8
294131095360701	LJ–65–20–407	8/6/2008	1540	Environmental	6.7	<.1	526	<.04	4.6	<1.8	<.6	<1.8
294147095344303	LJ–65–20–513	8/7/2008	0940	Environmental	3.6	<.1	582	<.04	5.8	2.7	<.6	<1.8
294144095351002	LJ–65–20–409	8/7/2008	1205	Environmental	4.2	<.1	561	<.04	5.1	3.0	<.6	<1.8
294149095363002	LJ–65–20–408	8/7/2008	1410	Environmental	5.7	<.1	597	<.04	1.9	5.7	<.6	<1.8
295228095262901	LJ–65–13–220	8/11/2008	1105	Environmental	25.1	<.1	659	<.04	7.6	3.6	<.6	<1.8
295228095263101	LJ–65–13–222	8/11/2008	1350	Environmental	<.04	<.1	216	<.04	.12	<1.8	<.6	<1.8
295228095263101	LJ–65–13–222	8/11/2008	1351	Sequential replicate	<.04	<.1	223	<.04	.16	<1.8	--	--
295207095262102	LJ–65–13–221	8/12/2008	1035	Environmental	.63	<.1	236	<.04	3.3	3.0	<.6	<1.8
295306095270502	LJ–65–05–813	8/12/2008	1350	Environmental	4.3	<.1	588	<.04	2.4	5.6	<.6	<1.8
295150095254601	LJ–65–13–214	8/13/2008	1030	Environmental	2.9	<.1	618	<.04	5.7	<1.8	<.6	<1.8
295150095254601	LJ–65–13–214	8/13/2008	1031	Sequential replicate	2.9	<.1	615	<.04	5.7	<1.8	<.6	<1.8
295251095264502	LJ–65–05–814	8/13/2008	1350	Environmental	12.7	<.1	617	<.04	.84	12.3	<.6	<1.8
295203095261401	LJ–65–13–224	8/14/2008	1030	Environmental	<.04	<.1	222	<.04	.15	<1.8	<.6	<1.8
295203095261401	LJ–65–13–224	8/14/2008	1031	Sequential replicate	--	--	--	--	--	--	<.6	<1.8
295204095261301	LJ–65–13–225	8/14/2008	1305	Environmental	.09	<.1	626	<.04	.20	<1.8	<.6	<1.8

Table 8. Results of radionuclide analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08.

[Rounding of each radionuclide result is unique, based on significant digits of the associated combined standard uncertainty (CSU). Th, thorium; pCi/L, picocuries per liter; ssL_C, sample-specific critical level; R, nondetected result less than ssL_C; a, negative result may indicate potential negative bias; b, sample-specific minimum detectable concentration greater than contractually preestablished method detectable concentration; --, no data available; c, laboratory control sample recovery outside contractually acceptable range; Cs, cesium; <, less than; ssMDC, sample-specific minimum detectable concentration; d, yield outside contractually acceptable range; MRL, minimum reporting level; µg/L, micrograms per liter; E, estimated]

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Alpha radio-activity, 30-day count, water, filtered, Th-230 curve (pCi/L)[1]	Alpha radio-activity, 30-day count, 1-sigma CSU, water, filtered, Th-230 curve (pCi/L)	Alpha radio-activity, 30-day count, ssL_C, water, filtered, Th-230 curve (pCi/L)	Alpha radioactivity, 30-day count, remark code	Alpha radioactivity, 72-hour count, water, filtered, Th-230 curve (pCi/L)[1]	Alpha radioactivity, 72-hour count, 1-sigma CSU, water, filtered, Th-230 curve (pCi/L)	Alpha radioactivity, 72-hour count, ssL_C, water, filtered, Th-230 curve (pCi/L)	Alpha radioactivity, 72-hour count, remark code
					Wells sampled in 2007							
300419095154301	TS–60–62–604	6/25/2007	1130	Environmental	-0.94	0.81	1.40	R	-1.1	1.3	2.1	R
300419095154301	TS–60–62–604	6/25/2007	1131	Sequential replicate	.28	.65	1.00	R	-2.5	1.1	2.0	R,a
300258095145301	TS–60–63–404	6/25/2007	1430	Environmental	-.03	.46	.72	R	.75	.80	1.20	R
300359095122902	LJ–60–63–510	6/26/2007	0945	Environmental	.48	.41	.56	R	1.6	1.0	1.2	b
300302095113301	LJ–60–63–511	6/26/2007	1145	Environmental	3.68	.70	.48	--	5.51	.97	.79	--
300355095093501	LJ–60–63–602	6/26/2007	1345	Environmental	5.2	1.4	1.0	--	5.0	1.6	1.5	b
300225095144202	LJ–60–63–709	6/27/2007	0910	Environmental	2.60	.79	.92	--	2.55	.98	1.40	--
300231095113701	LJ–60–63–508	6/27/2007	1120	Environmental	-.26	.65	1.00	R	5.4	1.5	1.0	--
300334095113401	LJ–60–63–504	6/27/2007	1400	Environmental	-.47	.55	.92	R	1.44	.57	.71	--
300403095125402	LJ–60–63–502	6/28/2007	0900	Environmental	-.13	.45	.72	R	4.81	.85	.59	--
300426095123902	LJ–60–63–407	6/28/2007	1140	Environmental	.04	.60	.97	R	6.1	1.0	.7	--
300426095123902	LJ–60–63–407	6/28/2007	1141	Sequential replicate	.31	.65	1.00	R	4.89	.94	.81	--
300408095115201	LJ–60–63–503	7/9/2007	0920	Environmental	6.3	1.2	.7	c	5.7	1.6	1.3	b
300446095121901	TS–60–63–507	7/9/2007	1200	Environmental	3.08	.67	.65	c	4.38	.83	.70	--
300343095090301	LJ–60–63–604	7/10/2007	0925	Environmental	-.19	.65	.98	R,c	2.75	.75	.81	--
300248095105301	LJ–60–63–505	7/10/2007	1120	Environmental	.70	.50	.79	R,c	3.87	.71	.51	--
300248095105301	LJ–60–63–505	7/10/2007	1121	Sequential replicate	.52	.60	.87	R,c	5.01	.86	.60	--

Table 8. Results of radionuclide analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Alpha radio-activity, 30-day count, water, filtered, Th-230 curve (pCi/L)[1]	Alpha radio-activity, 30-day count, 1-sigma CSU, water, filtered, Th-230 curve (pCi/L)	Alpha radio-activity, 30-day count, ssL_c, water, filtered, Th-230 curve (pCi/L)	Alpha radioactiv-ity, 30-day count, remark code	Alpha radioactiv-ity, 72-hour count, water, filtered, Th-230 curve (pCi/L)[1]	Alpha radioactiv-ity, 72-hour count, 1-sigma CSU, water, filtered, Th-230 curve (pCi/L)	Alpha radioactiv-ity, 72-hour count, ssL_c, water, filtered, Th-230 curve (pCi/L)	Alpha radioactiv-ity, 72-hour count, remark code
Wells sampled in 2008												
294113095361701	LJ–65–20–421	8/6/2008	1055	Environmental	4.0	1.1	1.0	--	3.36	0.74	0.62	--
294113095361702	LJ–65–20–422	8/6/2008	1330	Environmental	15.5	2.0	.6	--	17.2	2.2	.6	--
294131095360701	LJ–65–20–407	8/6/2008	1540	Environmental	5.6	1.4	1.0	--	13.2	1.9	.8	--
294147095344303	LJ–65–20–513	8/7/2008	0940	Environmental	7.6	1.4	.9	--	16.4	2.2	.7	--
294144095351002	LJ–65–20–409	8/7/2008	1205	Environmental	8.6	1.4	.9	--	15.9	2.2	.8	--
294149095363002	LJ–65–20–408	8/7/2008	1410	Environmental	4.64	.98	.71	--	10.3	1.6	.8	--
295228095262901	LJ–65–13–220	8/11/2008	1105	Environmental	8.0	1.5	.9	--	9.9	1.4	.5	--
295228095263101	LJ–65–13–222	8/11/2008	1350	Environmental	2.50	.79	.72	--	2.4	1.0	1.2	--
295228095263101	LJ–65–13–222	8/11/2008	1351	Sequential replicate	1.08	.71	.87	--	1.88	.77	.79	--
295207095262102	LJ–65–13–221	8/12/2008	1035	Environmental	3.0	1.1	1.1	--	8.4	1.4	.8	--
295306095270502	LJ–65–05–813	8/12/2008	1350	Environmental	13.3	1.9	.8	--	14.7	2.1	.8	--
295150095254601	LJ–65–13–214	8/13/2008	1030	Environmental	5.8	1.4	1.0	--	11.4	1.7	1.0	--
295150095254601	LJ–65–13–214	8/13/2008	1031	Sequential replicate	8.5	2.6	3.1	b	10.2	1.5	.6	--
295251095264502	LJ–65–05–814	8/13/2008	1350	Environmental	8.2	1.4	.9	--	13.3	1.9	.8	--
295203095261401	LJ–65–13–224	8/14/2008	1030	Environmental	-.24	.70	1.10	R	1.19	.76	.95	--
295203095261401	LJ–65–13–224	8/14/2008	1031	Sequential replicate	2.52	.98	1.20	--	2.31	.83	.91	--
295204095261301	LJ–65–13–225	8/14/2008	1305	Environmental	7.2	1.5	1.0	--	12.0	1.8	1.2	--

Table 8. Results of radionuclide analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Beta radioactivity, 30-day count, water, filtered, Cs-137 curve (pCi/L)[1]	Beta radioactivity, 30-day count, 1-sigma CSU, water, filtered, Cs-137 curve (pCi/L)	Beta radioactivity, 30-day count, ssL$_C$, water, filtered, Cs-137 curve (pCi/L)	Beta radioactivity, 30-day count, remark code	Beta radioactivity, 72-hour count, water, filtered, Cs-137 curve (pCi/L)[1]	Beta radioactivity, 72-hour count, 1-sigma CSU, water, filtered, Cs-137 curve (pCi/L)	Beta radioactivity, 72-hour count, ssL$_C$, water, filtered, Cs-137 curve (pCi/L)	Beta radioactivity, 72-hour count, remark code
					Wells sampled in 2007							
300419095154301	TS–60–62–604	6/25/2007	1130	Environmental	-0.78	0.70	1.20	R	1.96	0.68	1.00	--
300419095154301	TS–60–62–604	6/25/2007	1131	Sequential replicate	1.18	.61	.94	--	1.36	.62	.97	--
300258095145301	TS–60–63–404	6/25/2007	1430	Environmental	3.67	.66	.77	--	3.36	.82	1.20	--
300359095122902	LJ–60–63–510	6/26/2007	0945	Environmental	2.11	.39	.47	--	2.87	.76	.97	--
300302095113301	LJ–60–63–511	6/26/2007	1145	Environmental	2.52	.42	.48	--	2.71	.56	.77	--
300355095093501	LJ–60–63–602	6/26/2007	1345	Environmental	5.71	.94	.94	--	6.60	1.3	1.6	--
300225095144202	LJ–60–63–709	6/27/2007	0910	Environmental	8.3	1.0	.7	--	3.00	.67	.94	--
300231095113701	LJ–60–63–508	6/27/2007	1120	Environmental	3.80	.84	1.10	--	2.19	.64	.88	--
300334095113401	LJ–60–63–504	6/27/2007	1400	Environmental	2.15	.59	.85	--	2.38	.42	.51	--
300403095125402	LJ–60–63–502	6/28/2007	0900	Environmental	1.31	.43	.64	--	2.54	.45	.52	--
300426095123902	LJ–60–63–407	6/28/2007	1140	Environmental	3.48	.56	.65	--	3.16	.55	.66	--
300426095123902	LJ–60–63–407	6/28/2007	1141	Sequential replicate	2.94	.62	.87	--	3.75	.55	.56	--
300408095115201	LJ–60–63–503	7/9/2007	0920	Environmental	4.45	.67	.66	--	4.29	.86	.96	--
300446095121901	TS–60–63–507	7/9/2007	1200	Environmental	3.96	.57	.57	--	5.60	.71	.55	--
300343095090301	LJ–60–63–604	7/10/2007	0925	Environmental	2.87	.48	.57	--	3.38	.56	.64	--
300248095105301	LJ–60–63–505	7/10/2007	1120	Environmental	3.01	.45	.48	--	3.95	.52	.46	--
300248095105301	LJ–60–63–505	7/10/2007	1121	Sequential replicate	4.07	.68	.82	--	3.60	.52	.51	--

Table 8. Results of radionuclide analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Beta radioactivity, 30-day count, water, filtered, Cs-137 curve (pCi/L)[1]	Beta radioactivity, 30-day count, 1-sigma CSU, water, filtered, Cs-137 curve (pCi/L)	Beta radioactivity, 30-day count, ssL_C, water, filtered, Cs-137 curve (pCi/L)	Beta radioactivity, 30-day count, remark code	Beta radioactivity, 72-hour count, water, filtered, Cs-137 curve (pCi/L)[1]	Beta radioactivity, 72-hour count, 1-sigma CSU, water, filtered, Cs-137 curve (pCi/L)	Beta radioactivity, 72-hour count, ssL_C, water, filtered, Cs-137 curve (pCi/L)	Beta radioactivity, 72-hour count, remark code
Wells sampled in 2008												
294113095361701	LJ–65–20–421	8/6/2008	1055	Environmental	2.38	0.66	1.10	--	2.10	0.51	0.78	--
294113095361702	LJ–65–20–422	8/6/2008	1330	Environmental	10.4	1.0	1.2	--	3.64	.52	.68	--
294131095360701	LJ–65–20–407	8/6/2008	1540	Environmental	5.52	.86	1.00	--	2.62	.57	.80	--
294147095344303	LJ–65–20–513	8/7/2008	0940	Environmental	3.86	.73	1.10	--	4.11	.64	.84	--
294144095351002	LJ–65–20–409	8/7/2008	1205	Environmental	2.27	.41	.59	--	3.72	.41	.48	--
294149095363002	LJ–65–20–408	8/7/2008	1410	Environmental	-1.04	.60	1.00	R,a	2.91	.62	.91	--
295228095262901	LJ–65–13–220	8/11/2008	1105	Environmental	4.17	.69	.90	--	4.55	.74	1.00	--
295228095263101	LJ–65–13–222	8/11/2008	1350	Environmental	.81	.75	1.20	R	2.09	.71	1.10	--
295228095263101	LJ–65–13–222	8/11/2008	1351	Sequential replicate	2.98	.62	.86	--	1.71	.61	.90	--
295207095262102	LJ–65–13–221	8/12/2008	1035	Environmental	2.2	1.2	1.8	--	2.24	.52	.75	--
295306095270502	LJ–65–05–813	8/12/2008	1350	Environmental	7.06	.89	1.20	--	3.55	.58	.75	--
295150095254601	LJ–65–13–214	8/13/2008	1030	Environmental	4.75	.75	.91	--	3.55	.54	.72	--
295150095254601	LJ–65–13–214	8/13/2008	1031	Sequential replicate	4.83	.80	1.00	--	3.00	.77	1.10	--
295251095264502	LJ–65–05–814	8/13/2008	1350	Environmental	4.89	.61	.71	--	3.91	.64	.88	--
295203095261401	LJ–65–13–224	8/14/2008	1030	Environmental	1.88	.51	.76	--	1.48	.48	.78	--
295203095261401	LJ–65–13–224	8/14/2008	1031	Sequential replicate	4.56	.79	1.10	--	.64	.31	.50	--
295204095261301	LJ–65–13–225	8/14/2008	1305	Environmental	.16	.80	1.30	R	3.42	.58	.79	--

Table 8. Results of radionuclide analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Carbon-14 counting error, water, filtered, percent modern	Carbon-14, water, filtered, percent modern	Carbon-14 analysis remark code	Carbon-13/carbon-12 ratio, water, unfiltered (per mil)	Carbon-13/carbon-12 ratio remark code	Radium-226, water, filtered, radon method (pCi/L)	Radium-226, 1-sigma CSU, water, filtered, radon method (pCi/L)	Radium-226, ssL_c, water, filtered, radon method (pCi/L)	Radium-226 remark code
Wells sampled in 2007													
300419095154301	TS–60–62–604	6/25/2007	1130	Environmental	--	--	--	--	--	0.204	0.020	0.013	--
300419095154301	TS–60–62–604	6/25/2007	1131	Sequential replicate	--	--	--	--	--	.195	.019	.010	--
300258095145301	TS–60–63–404	6/25/2007	1430	Environmental	--	--	--	--	--	.371	.026	.011	--
300359095122902	LJ–60–63–510	6/26/2007	0945	Environmental	--	--	--	--	--	.420	.027	.017	--
300302095113301	LJ–60–63–511	6/26/2007	1145	Environmental	--	--	--	--	--	2.655	.089	.015	--
300355095093501	LJ–60–63–602	6/26/2007	1345	Environmental	--	--	--	--	--	.736	.043	.014	--
300225095144202	LJ–60–63–709	6/27/2007	0910	Environmental	--	--	--	--	--	.853	.045	.015	--
300231095113701	LJ–60–63–508	6/27/2007	1120	Environmental	--	--	--	--	--	.733	.044	.013	--
300334095113401	LJ–60–63–504	6/27/2007	1400	Environmental	--	--	--	--	--	.406	.033	.014	--
300403095125402	LJ–60–63–502	6/28/2007	0900	Environmental	--	--	--	--	--	.397	.031	.013	--
300426095123902	LJ–60–63–407	6/28/2007	1140	Environmental	--	--	--	--	--	1.179	.056	.013	--
300426095123902	LJ–60–63–407	6/28/2007	1141	Sequential replicate	--	--	--	--	--	1.108	.049	.014	--
300408095115201	LJ–60–63–503	7/9/2007	0920	Environmental	--	--	--	--	--	1.151	.050	.014	--
300446095121901	TS–60–63–507	7/9/2007	1200	Environmental	--	--	--	--	--	.463	.030	.015	--
300343095090301	LJ–60–63–604	7/10/2007	0925	Environmental	--	--	--	--	--	.262	.023	.017	--
300248095105301	LJ–60–63–505	7/10/2007	1120	Environmental	--	--	--	--	--	.381	.026	.013	--
300248095105301	LJ–60–63–505	7/10/2007	1121	Sequential replicate	--	--	--	--	--	.266	.022	.015	--

Table 8. Results of radionuclide analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Carbon-14 counting error, water, filtered, percent modern	Carbon-14, water, filtered, percent modern	Carbon-14 analysis remark code	Carbon-13/carbon-12 ratio, water, unfiltered (per mil)	Carbon-13/carbon-12 ratio remark code	Radium-226, water, filtered, radon method (pCi/L)	Radium-226, 1-sigma CSU, water, filtered, radon method (pCi/L)	Radium-226, ssL_c, water, filtered, radon method (pCi/L)	Radium-226 remark code
Wells sampled in 2008													
294113095361701	LJ–65–20–421	8/6/2008	1055	Environmental	0.10	0.96	--	-10.89	--	0.912	0.085	0.014	--
294113095361702	LJ–65–20–422	8/6/2008	1330	Environmental	.12	3.75	--	-11.16	--	1.65	.15	.02	--
294131095360701	LJ–65–20–407	8/6/2008	1540	Environmental	--	--	--	--	--	.770	.073	.015	--
294147095344303	LJ–65–20–513	8/7/2008	0940	Environmental	.14	4.67	--	-10.56	--	.799	.076	.016	--
294144095351002	LJ–65–20–409	8/7/2008	1205	Environmental	--	--	--	--	--	.826	.076	.009	--
294149095363002	LJ–65–20–408	8/7/2008	1410	Environmental	.14	5.09	--	-11.43	--	.906	.083	.013	--
295228095262901	LJ–65–13–220	8/11/2008	1105	Environmental	--	--	--	--	--	.397	.042	.015	--
295228095263101	LJ–65–13–222	8/11/2008	1350	Environmental	--	.33	<	-11.64	--	.281	.033	.017	--
295228095263101	LJ–65–13–222	8/11/2008	1351	Sequential replicate	.10	.33	--	-10.72	--	.261	.030	.016	--
295207095262102	LJ–65–13–221	8/12/2008	1035	Environmental	.23	30.73	--	-9.20	--	.389	.038	.016	--
295306095270502	LJ–65–05–813	8/12/2008	1350	Environmental	--	--	--	--	--	.676	.062	.012	--
295150095254601	LJ–65–13–214	8/13/2008	1030	Environmental	.12	4.59	--	-11.16	--	.384	.039	.012	--
295150095254601	LJ–65–13–214	8/13/2008	1031	Sequential replicate	.12	4.50	--	-11.55	--	.285	.030	.012	--
295251095264502	LJ–65–05–814	8/13/2008	1350	Environmental	.12	3.89	--	-11.64	--	.978	.088	.013	--
295203095261401	LJ–65–13–224	8/14/2008	1030	Environmental	--	.37	<	-11.57	--	.273	.030	.013	--
295203095261401	LJ–65–13–224	8/14/2008	1031	Sequential replicate	--	.24	<	-11.81	--	.294	.031	.012	--
295204095261301	LJ–65–13–225	8/14/2008	1305	Environmental	--	--	--	--	--	2.44	.21	.01	--

Table 8. Results of radionuclide analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Radium-228, water, filtered (pCi/L)	Radium-228, 1-sigma CSU, water, filtered (pCi/L)	Radium-228, ssL$_c$, water, filtered (pCi/L)	Radium-228, remark code	Radon-222, water, unfiltered (pCi/L)	Radon-222, 2-sigma CSU, water, unfiltered (pCi/L)	Radon-222, ssMDC, water, unfiltered (pCi/L)	Radon-222, 1-sigma CSU, water, unfiltered (pCi/L)	Radon-222, ssL$_c$, water, unfiltered, (pCi/L)
					Wells sampled in 2007								
300419095154301	TS–60–62–604	6/25/2007	1130	Environmental	0.042	0.075	0.180	R	700	26	22	--	--
300419095154301	TS–60–62–604	6/25/2007	1131	Sequential replicate	.157	.070	.180	R	700	26	22	--	--
300258095145301	TS–60–63–404	6/25/2007	1430	Environmental	.15	.20	.19	R	360	21	22	--	--
300359095122902	LJ–60–63–510	6/26/2007	0945	Environmental	.45	.11	.24	--	710	27	23	--	--
300302095113301	LJ–60–63–511	6/26/2007	1145	Environmental	.577	.096	.210	--	830	28	23	--	--
300355095093501	LJ–60–63–602	6/26/2007	1345	Environmental	.49	.10	.22	--	380	22	23	--	--
300225095144202	LJ–60–63–709	6/27/2007	0910	Environmental	.47	.10	.22	--	520	24	24	--	--
300231095113701	LJ–60–63–508	6/27/2007	1120	Environmental	.37	.11	.25	--	480	24	24	--	--
300334095113401	LJ–60–63–504	6/27/2007	1400	Environmental	.55	.16	.31	--	370	22	24	--	--
300403095125402	LJ–60–63–502	6/28/2007	0900	Environmental	.277	.080	.190	--	380	21	22	--	--
300426095123902	LJ–60–63–407	6/28/2007	1140	Environmental	.491	.076	.170	--	730	26	22	--	--
300426095123902	LJ–60–63–407	6/28/2007	1141	Sequential replicate	.52	.12	.20	--	770	27	23	--	--
300408095115201	LJ–60–63–503	7/9/2007	0920	Environmental	.619	.091	.190	--	770	27	23	--	--
300446095121901	TS–60–63–507	7/9/2007	1200	Environmental	.465	.081	.180	--	760	27	23	--	--
300343095090301	LJ–60–63–604	7/10/2007	0925	Environmental	.238	.080	.190	--	300	20	23	--	--
300248095105301	LJ–60–63–505	7/10/2007	1120	Environmental	.96	.13	.26	--	240	19	23	--	--
300248095105301	LJ–60–63–505	7/10/2007	1121	Sequential replicate	.297	.080	.180	--	270	19	23	--	--

Table 8. Results of radionuclide analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Radium-228, water, filtered (pCi/L)	Radium-228, 1-sigma CSU, water, filtered (pCi/L)	Radium-228, ssL_c, water, filtered (pCi/L)	Radium-228, remark code	Radon-222, water, unfiltered (pCi/L)	Radon-222, 2-sigma CSU, water, unfiltered (pCi/L)	Radon-222, ssMDC, water, unfiltered (pCi/L)	Radon-222, 1-sigma CSU, water, unfiltered (pCi/L)	Radon-222, ssL_c, water, unfiltered, (pCi/L)
Wells sampled in 2008													
294113095361701	LJ–65–20–421	8/6/2008	1055	Environmental	0.41	0.11	0.24	--	1,140	--	--	65	11
294113095361702	LJ–65–20–422	8/6/2008	1330	Environmental	.75	.15	.23	--	560	--	--	34	11
294131095360701	LJ–65–20–407	8/6/2008	1540	Environmental	1.03	.15	.28	d	280	--	--	20	11
294147095344303	LJ–65–20–513	8/7/2008	0940	Environmental	.95	.13	.24	--	470	--	--	29	11
294144095351002	LJ–65–20–409	8/7/2008	1205	Environmental	1.10	.14	.26	--	273	--	--	19	11
294149095363002	LJ–65–20–408	8/7/2008	1410	Environmental	.70	.15	.27	d	540	--	--	33	11
295228095262901	LJ–65–13–220	8/11/2008	1105	Environmental	.67	.16	.27	c,d	254	--	--	18	11
295228095263101	LJ–65–13–222	8/11/2008	1350	Environmental	-.04	.12	.31	R,c,d	800	--	--	46	12
295228095263101	LJ–65–13–222	8/11/2008	1351	Sequential replicate	.20	.12	.30	R,c,d	650	--	--	39	12
295207095262102	LJ–65–13–221	8/12/2008	1035	Environmental	.65	.13	.27	d	161	--	--	13	10
295306095270502	LJ–65–05–813	8/12/2008	1350	Environmental	-.18	.10	.27	R,a,d	570	--	--	34	10
295150095254601	LJ–65–13–214	8/13/2008	1030	Environmental	.46	.12	.26	--	1,200	--	--	68	12
295150095254601	LJ–65–13–214	8/13/2008	1031	Sequential replicate	.48	.12	.26	--	1,150	--	--	65	12
295251095264502	LJ–65–05–814	8/13/2008	1350	Environmental	.38	.11	.24	--	870	--	--	50	12
295203095261401	LJ–65–13–224	8/14/2008	1030	Environmental	.18	.12	.28	R	630	--	--	38	11
295203095261401	LJ–65–13–224	8/14/2008	1031	Sequential replicate	.27	.12	.28	R	620	--	--	37	11
295204095261301	LJ–65–13–225	8/14/2008	1305	Environmental	.37	.12	.28	--	2,230	--	--	120	11

Table 8. Results of radionuclide analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Tritium, water, unfiltered (pCi/L)	Tritium, 2-sigma CSU, water, unfiltered (pCi/L)	Tritium, MRL, water, unfiltered (pCi/L)	Tritium, 1-sigma CSU, water, unfiltered (pCi/L)	Tritium, ssL_C, water, unfiltered (pCi/L)	Tritium, water, unfiltered, remark code	Uranium (natural), water, filtered (µg/L)	Uranium (natural), LRL, water, filtered (µg/L)	Uranium (natural) remark code
Wells sampled in 2007													
300419095154301	TS–60–62–604	6/25/2007	1130	Environmental	0.10	0.58	0.30	--	--	--	0.04	0.04	<
300419095154301	TS–60–62–604	6/25/2007	1131	Sequential replicate	-.10	.58	.30	--	--	--	.04	.04	<
300258095145301	TS–60–63–404	6/25/2007	1430	Environmental	.35	.58	.30	--	--	--	.13	.04	--
300359095122902	LJ–60–63–510	6/26/2007	0945	Environmental	-.42	.58	.30	--	--	--	.04	.04	<
300302095113301	LJ–60–63–511	6/26/2007	1145	Environmental	-.16	.58	.30	--	--	--	.06	.04	--
300355095093501	LJ–60–63–602	6/26/2007	1345	Environmental	-.13	.58	.30	--	--	--	3.97	.04	--
300225095144202	LJ–60–63–709	6/27/2007	0910	Environmental	.06	.58	.30	--	--	--	.66	.04	--
300231095113701	LJ–60–63–508	6/27/2007	1120	Environmental	.13	.58	.30	--	--	--	.02	.04	E
300334095113401	LJ–60–63–504	6/27/2007	1400	Environmental	-.16	.58	.30	--	--	--	.04	.04	<
300403095125402	LJ–60–63–502	6/28/2007	0900	Environmental	.16	.58	.30	--	--	--	.04	.04	<
300426095123902	LJ–60–63–407	6/28/2007	1140	Environmental	-.10	.58	.30	--	--	--	.02	.04	E
300426095123902	LJ–60–63–407	6/28/2007	1141	Sequential replicate	.10	.58	.30	--	--	--	.02	.04	E
300408095115201	LJ–60–63–503	7/9/2007	0920	Environmental	.32	.58	.30	--	--	--	.03	.04	E
300446095121901	TS–60–63–507	7/9/2007	1200	Environmental	-.29	.58	.30	--	--	--	.02	.04	E
300343095090301	LJ–60–63–604	7/10/2007	0925	Environmental	-.35	.58	.30	--	--	--	.38	.04	--
300248095105301	LJ–60–63–505	7/10/2007	1120	Environmental	.10	.58	.30	--	--	--	.04	.04	<
300248095105301	LJ–60–63–505	7/10/2007	1121	Sequential replicate	.06	.58	.30	--	--	--	--	--	--

Table 8. Results of radionuclide analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

U.S. Geological Survey site number	State well number	Date	Sample start time	Sample type	Tritium, water, unfiltered (pCi/L)	Tritium, 2-sigma CSU, water, unfiltered (pCi/L)	Tritium, MRL, water, unfiltered (pCi/L)	Tritium, 1-sigma CSU, water, unfiltered (pCi/L)	Tritium, ssL$_C$, water, unfiltered (pCi/L)	Tritium, water, unfiltered, remark code	Uranium (natural), water, filtered (µg/L)	Uranium (natural), LRL, water, filtered (µg/L)	Uranium (natural) remark code
Wells sampled in 2008													
294113095361701	LJ–65–20–421	8/6/2008	1055	Environmental	-.29	--	--	0.29	0.29	R	0.12	0.02	--
294113095361702	LJ–65–20–422	8/6/2008	1330	Environmental	-0.10	--	--	.29	.29	R	17.4	.02	--
294131095360701	LJ–65–20–407	8/6/2008	1540	Environmental	-.03	--	--	.29	.29	R	6.69	.02	--
294147095344303	LJ–65–20–513	8/7/2008	0940	Environmental	.22	--	--	.29	.29	R	6.75	.02	--
294144095351002	LJ–65–20–409	8/7/2008	1205	Environmental	-.26	--	--	.29	.29	R	5.65	.02	--
294149095363002	LJ–65–20–408	8/7/2008	1410	Environmental	-.10	--	--	.29	.29	R	4.41	.02	--
295228095262901	LJ–65–13–220	8/11/2008	1105	Environmental	.42	--	--	.29	.29	--	7.50	.02	--
295228095263101	LJ–65–13–222	8/11/2008	1350	Environmental	.06	--	--	.29	.29	R	0.02	.02	<
295228095263101	LJ–65–13–222	8/11/2008	1351	Sequential replicate	.16	--	--	.29	.29	R	0.02	.02	<
295207095262102	LJ–65–13–221	8/12/2008	1035	Environmental	-.06	--	--	.29	.29	R	1.15	.02	--
295306095270502	LJ–65–05–813	8/12/2008	1350	Environmental	.03	--	--	.29	.29	R	10.1	.02	--
295150095254601	LJ–65–13–214	8/13/2008	1030	Environmental	.00	--	--	.29	.29	R	7.77	.02	--
295150095254601	LJ–65–13–214	8/13/2008	1031	Sequential replicate	.06	--	--	.29	.29	R	7.67	.02	--
295251095264502	LJ–65–05–814	8/13/2008	1350	Environmental	.13	--	--	.29	.29	R	6.47	.02	--
295203095261401	LJ–65–13–224	8/14/2008	1030	Environmental	.06	--	--	.29	.29	R	0.02	.02	<
295203095261401	LJ–65–13–224	8/14/2008	1031	Sequential replicate	-.06	--	--	.29	.29	R	--	--	--
295204095261301	LJ–65–13–225	8/14/2008	1305	Environmental	.10	--	--	.29	.29	R	1.05	.02	--

[1] All time dependent analyses were completed within holding time limit. Analyses for alpha and beta radioactivity, 30-day count, were completed within 31 to 49 days after sample collection.

Table 9. Minimum, median, and maximum concentrations for physicochemical properties, major ions, arsenic, trace elements, and radionuclide analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08.

[nm, nanometers; NTRU, Nephelometric Turbidity Ratio Unit; mg/L, milligrams per liter; °C, degrees Celsius; <, less than; $CaCO_3$, calcium carbonate; µg/L, micrograms per liter; µg-As/L, micrograms arsenic per liter; Th, thorium; pCi/L, picocuries per liter; Cs, cesium; R, nondetected result less than sample-specific critical level; E, summed result includes a nondetection]

	Oxidation reduction potential (ORP), reference electrode not specified (millivolts)	Turbidity, water, unfiltered, broad band light source (400-680 nm), detectors at multiple angles including 90 +/- 30 degrees, ratiometric correction (NTRU)	Barometric pressure (millimeters of mercury)	Dissolved oxygen (DO), water, unfiltered (mg/L)	pH, water, unfiltered, field (standard units)	Specific conductance, water, unfiltered (microsiemens per centimeter at 25 °C)	Temperature, air (°C)	Temperature, water (°C)	Calcium, water, filtered (mg/L)	Magnesium, water, filtered (mg/L)	Potassium, water, filtered (mg/L)	Sodium, water, filtered (mg/L)
Minimum	-212	0.1	754	<0.1	7.2	314	27.0	23.5	8.23	1.99	1.47	14.2
Median	-84.6	.1	758	.2	7.6	517	34.2	25.7	40.5	4.24	2.28	32.8
Maximum	244	1.9	766	4.5	8.1	856	42.5	29.9	66.4	10.5	2.67	182

	Alkalinity, water, filtered, inflection-point titration method (incremental titration method), field (mg/L as $CaCO_3$)	Bicarbonate, water, filtered, inflection-point titration method (incremental titration method), field (mg/L)	Bromide, water, filtered (mg/L)	Chloride, water, filtered (mg/L)	Fluoride, water, filtered (mg/L)	Silica, water, filtered (mg/L as SiO_2)	Sulfate, water, filtered (mg/L)	Sulfide, water, unfiltered, field (mg/L)	Residue on evaporation, dried at 180 °C, water, filtered (mg/L)	Organic carbon (DOC), water, filtered (mg/L)	Chemical oxygen demand (COD), high level, water, unfiltered (mg/L)	Aluminum, water, filtered (µg/L)
Minimum	126	154	0.06	15.3	0.12	14.2	<0.18	<0.005	175	<0.4	<10	<1.6
Median	167	203	.12	42.4	.21	23.5	9.73	.006	294	<.4	<10	<1.6
Maximum	324	394	.32	85.4	1.34	26.8	17.2	<.20	496	<.4	<10	3.0

	Antimony, water, filtered (µg/L)	Arsenate ($H_2AsO_4^-$, As[V]), water, filtered (µg-As/L)	Arsenic, water, filtered (µg/L)	Arsenite (H_3AsO_3, As[III]), water, filtered (µg-As/L)	Barium, water, filtered (µg/L)	Beryllium, water, filtered (µg/L)	Boron, water, filtered (µg/L)	Cadmium, water, filtered (µg/L)	Chromium, water, filtered (µg/L)	Cobalt, water, filtered (µg/L)	Copper, water, filtered (µg/L)	Iron, water, filtered (µg/L)	Lead, water, filtered (µg/L)
Minimum	<0.06	<0.8	0.58	<0.6	110	<0.01	20	<0.04	<0.12	<0.02	<0.4	<6	<0.08
Median	<.14	<.8	2.5	1.1	276	<.06	46	<.04	<.12	<.04	<1.0	51	<.12
Maximum	<.14	3.3	15.3	14.9	408	<.06	548	.04	3.0	.07	3.3	265	1.05

Table 9. Minimum, median, and maximum concentrations for physicochemical properties, major ions, arsenic, trace elements, and radionuclide analyses of water samples collected from 28 municipal supply wells in the Houston, Texas, area, 2007–08—Continued.

	Lithium, water, filtered (µg/L)	Manganese, water, filtered (µg/L)	Molybdenum, water, filtered (µg/L)	Nickel, water, filtered (µg/L)	Selenium, water, filtered (µg/L)	Silver, water, filtered (µg/L)	Strontium, water, filtered (µg/L)	Thallium, water, filtered (µg/L)	Vanadium, water, filtered (µg/L)	Zinc, water, filtered (µg/L)	Dimethylarsinate ($(CH_3)_2HAsO_2$, DMA), water, filtered, recoverable (µg-As/L)	Monomethylarsonate ($(CH_3)HAsO_3^-$, MMA), water, filtered, recoverable (µg-As/L)
Minimum	5.0	<0.2	0.5	<0.06	<0.04	<0.1	202	<0.04	<0.04	<0.60	<0.6	<1.2
Median	10.7	7.6	2.3	.19	<.08	<.1	318	<.04	.18	<1.8	<.6	<1.8
Maximum	23.8	109	18.1	.70	25.1	<.1	659	<.04	10.8	12.3	<.6	<1.8

	Alpha radioactivity, 30-day count, water, filtered, Th-230 curve (pCi/L)	Alpha radioactivity, 72-hour count, water, filtered, Th-230 curve (pCi/L)	Beta radioactivity, 30-day count, water, filtered, Cs-137 curve (pCi/L)	Beta radioactivity, 72-hour count, water, filtered, Cs-137 curve, (pCi/L)	Carbon-14, water, filtered, percent modern	Carbon-13/carbon-12 ratio, water, unfiltered (per mil)	Radium-226, water, filtered, radon method (pCi/L)	Radium-228, water, filtered (pCi/L)	Combined Ra[1] (pCi/L)	Radon-222, water, unfiltered (pCi/L)	Tritium, water, unfiltered (pCi/L)	Uranium (natural), water, filtered (µg/L)
Minimum	R-0.94	R-1.1	R-1.04	1.48	<0.33	-11.64	0.204	R-0.18	E0.246	161	R-0.42	<0.02
Median	3.38	5.46	3.25	3.26	3.89	-11.16	.704	.47	1.16	550	R.02	.26
Maximum	15.5	17.2	10.4	6.60	30.73	-9.20	2.66	1.10	3.23	2,230	.42	17.4

[1] Sum of radium-226 and radium-228.

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