

## **Field Testing of Water-Distribution Systems at U.S. Marine Corps Base, Camp Lejeune, North Carolina, in Support of an Epidemiologic Study**

J. B. Sautner<sup>1</sup>, M. L. Maslia<sup>2</sup>, C. Valenzuela<sup>3</sup>, W. M. Grayman<sup>4</sup>, M. M. Aral<sup>5</sup>, and J. W. Green, Jr.<sup>6</sup>

<sup>1</sup>Environmental Health Scientist, ATSDR, 1600 Clifton Road, Mailstop E-32, Atlanta, Georgia 30333; PH (404) 498-0496; FAX (404) 498-0420; email: [jsautner@cdc.gov](mailto:jsautner@cdc.gov)

<sup>2</sup>Research Environmental Engineer, ATSDR, 1600 Clifton Road, Mailstop E-32, Atlanta, Georgia 30333; PH (404) 498-0415; FAX (404) 498-0069; email: [mmlasia@cdc.gov](mailto:mmlasia@cdc.gov)

<sup>3</sup>Post-Graduate Research Fellow, ORISE/ATSDR, 1600 Clifton Road, Mailstop E-32, Atlanta, Georgia 30333; PH (404) 498-0414; FAX (404) 498-0069; email: [cvalenzuela@cdc.gov](mailto:cvalenzuela@cdc.gov)

<sup>4</sup>W. M. Grayman Consulting Engineer, 321 Ritchie Avenue, Cincinnati, Ohio 45215; PH (513) 761-1722; FAX (513) 761-5289; email: [grayman@fuse.net](mailto:grayman@fuse.net)

<sup>5</sup>Director, Multimedia Environmental Simulations Laboratory, School of Civil and Environmental Engineering, Georgia Institute of Technology, Atlanta, Georgia 30332; PH (404) 894-2223; FAX (404) 894-5111; email: [maral@ce.gatech.edu](mailto:maral@ce.gatech.edu)

<sup>6</sup>Post-Graduate Research Fellow, ORIS/ATSDR, 1600 Clifton Road, Mailstop E-32, Atlanta, Georgia 30333; PH (404) 498-0413; FAX (404) 498-0069; email: [jwgreen@cdc.gov](mailto:jwgreen@cdc.gov)

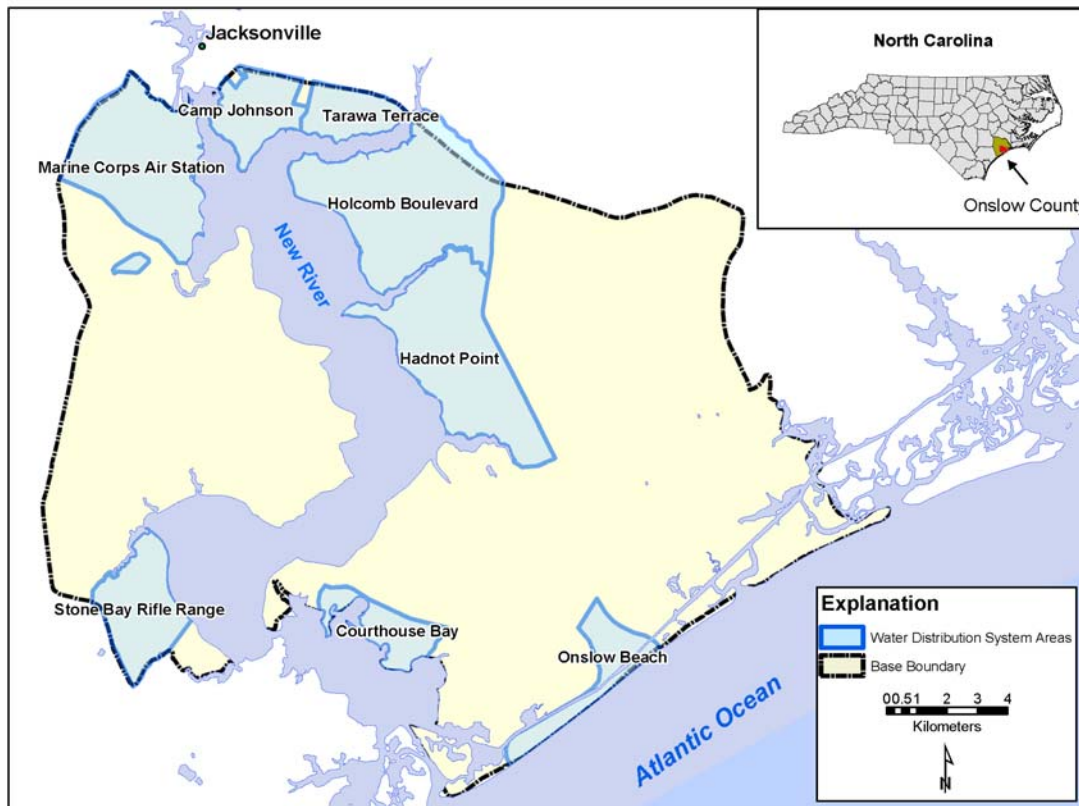
### ***Abstract***

An epidemiologic study is being conducted to determine if there is an association between exposure to contaminated drinking water and birth defects among children of women who lived at U.S. Marine Corps Base, Camp Lejeune, North Carolina while they were pregnant during 1968–1985. More than 12,000 pregnant women may have been exposed to well water contaminated with volatile organic compounds that was used for the potable water source and distributed through water-distribution systems at Camp Lejeune. Because of the paucity of historical water-distribution system operational data, information based on the operation of present-day water-distribution systems will be used for historical reconstruction. Present-day system operations will be modeled using water-distribution system models. To calibrate the models against hydraulic and water-quality parameters, field testing is being used to gather data and information on hydraulic, fate and transport, and operational characteristics of the water-distribution systems. Field activities include: (a) recording system pressures and storage tank water levels, and (b) conducting C-factor, fire-flow, tracer, and travel time tests. Because this is an ongoing and active investigation, the authors present an overview and summary of activities to date and some initial results from field-testing activities.

### ***Introduction***

When investigating childhood and rare diseases, epidemiologic studies explore a wide variety of risk factors, including environmental exposures. The Agency for Toxic Substances and Disease Registry (ATSDR) has determined that human exposure to groundwater contaminants occurred at U.S. Marine Corps Base (USMCB), Camp Lejeune,

North Carolina, prior to 1985 (ATSDR, 1990; 1997). To investigate this exposure, ATSDR is conducting an epidemiologic case-control study to determine if there is an association between exposure of children in utero to groundwater contaminated with volatile organic compounds (VOCs) and elevated rates of spina bifida, anencephaly, cleft lip, cleft palate, and childhood leukemia (ATSDR, 1998). Because of the paucity of historical, contaminant-specific data, water-distribution system models are being calibrated to present-day conditions before reconstructing historical concentrations. To assemble data necessary to calibrate the models, ATSDR, in cooperation with USMCB Camp Lejeune, has initiated a field-testing program to gather hydraulic, water-quality, and operational parameter data. To date, field-testing activities at Camp Lejeune have included: (a) recording system pressures and storage tank water levels, and (b) conducting C-factor, fire-flow, tracer, and travel time tests.

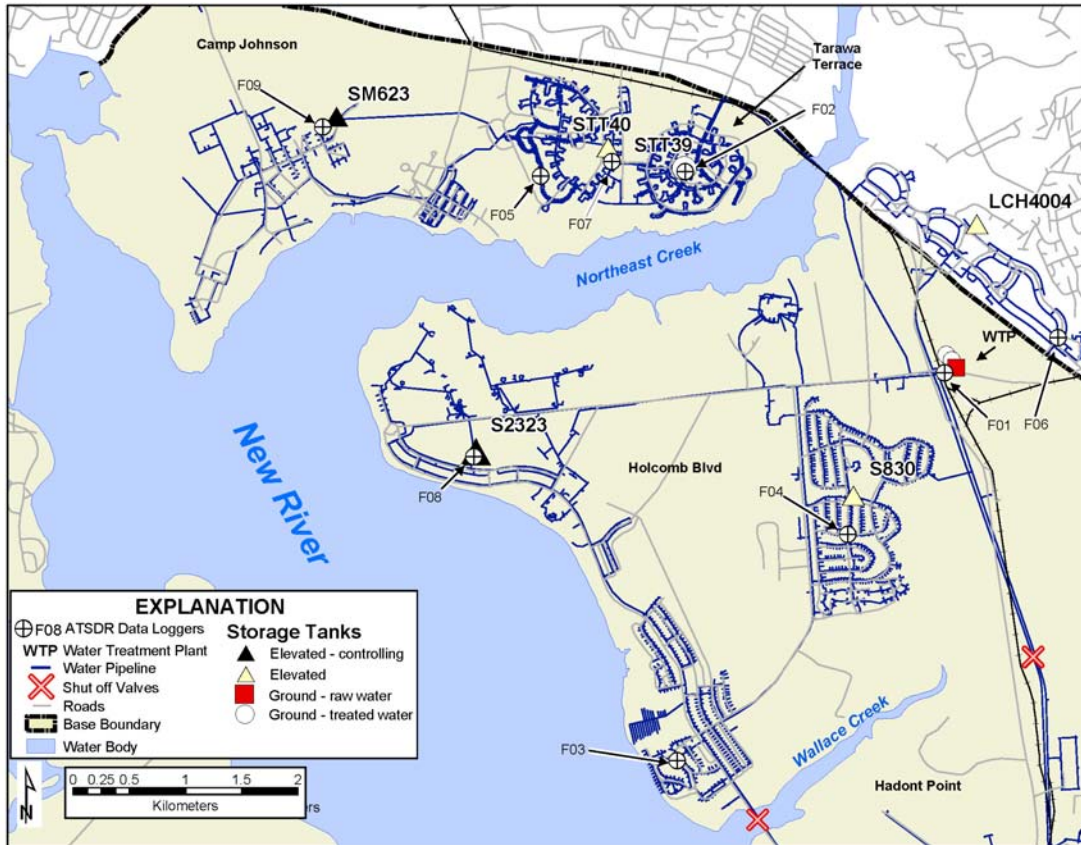


**Figure 1. Water-distribution systems serving U.S. Marine Corps Base, Camp Lejeune, North Carolina**

### *Study Area Description*

USMCB, Camp Lejeune encompasses an area of about 164 mi<sup>2</sup> (425 km<sup>2</sup>), and is located in Jacksonville, Onslow County, North Carolina, bordering the Atlantic Ocean. Historically, there have been eight water-distribution systems serving the base: (1) Onslow Beach, (2) Courthouse Bay, (3) Rifle Range, (4) Marine Corps Air Station, (5) Camp Johnson, (6) Tarawa Terrace, (7) Holcomb Boulevard, and (8) Hadnot Point (Figure 1). The focus of the epidemiologic study is on exposure from water-distribution systems that historically served the military base's housing—Camp Johnson, Tarawa Terrace, Holcomb Boulevard, and Hadnot Point. Presently, there are two operating water treatment plants

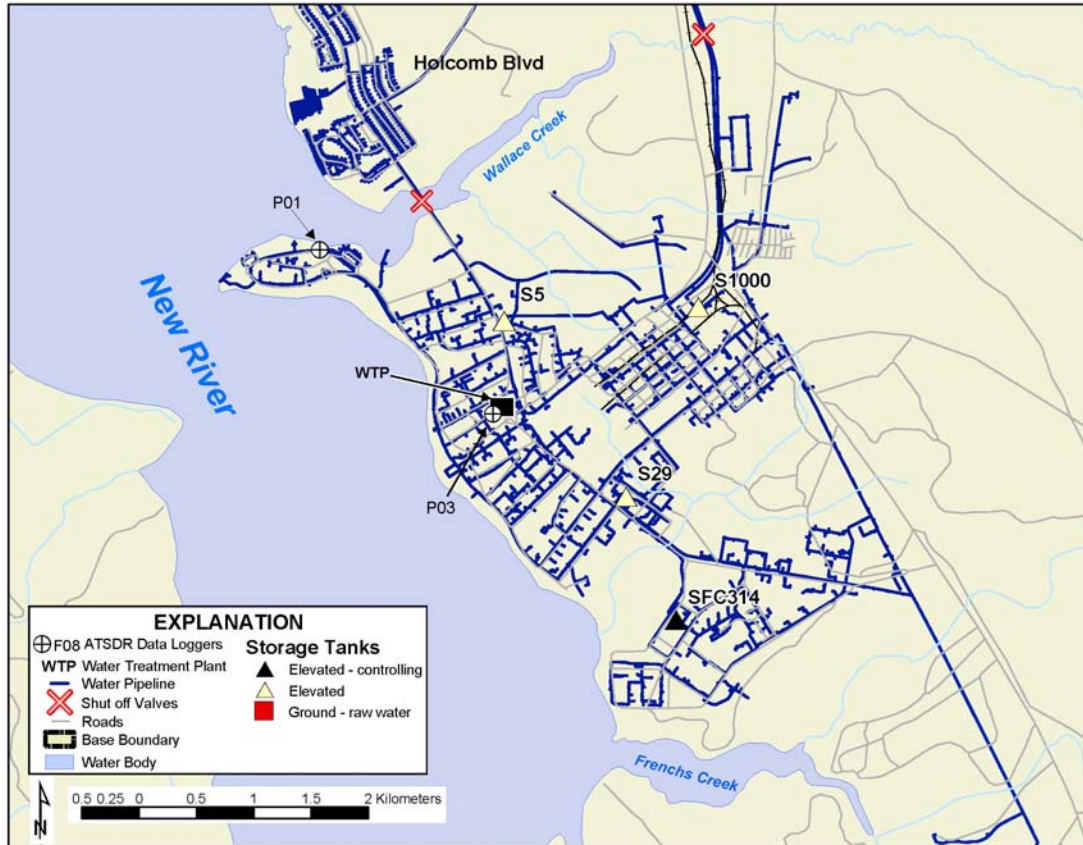
(WTP) that provide water for the distribution systems of interest to the epidemiologic study: (1) the Holcomb Boulevard WTP that services the Camp Johnson, Tarawa Terrace, and Holcomb Boulevard areas of the distribution system (Figure 2), and (2) the Hadnot Point WTP that services the Hadnot Point area of the distribution system (Figure 3).



**Figure 2. Holcomb Boulevard water treatment plant service area and water-distribution system**

Analysis of the water-distribution systems is complex because of historical changes in system configuration and operations. Hadnot Point was the original WTP and at one time, serviced the entire base. Thus, for the ATSDR study, it will be analyzed for both present-day and historical operations. The Holcomb Boulevard WTP presently services the rest of the military housing areas. The Tarawa Terrace WTP historically serviced the Tarawa Terrace and Camp Johnson areas. After the plant was shut down, the Holcomb Boulevard plant was used to service these areas. At present, there is a treated water reservoir (ground storage tank) at Tarawa Terrace (Figure 2) that receives water directly from the Holcomb Boulevard WTP.

Shut-off valves at two locations along Wallace Creek keep Hadnot Point water isolated from Holcomb Boulevard and Tarawa Terrace water. According to base water utility managers, valves have been opened only on very rare occasions, solely for emergency situations (S. A. Brewer, Camp Lejeune Environmental Management Division, written communication, November 19, 2004). Therefore, for purposes of the ATSDR study and water-distribution system analyses, it will be assumed that these valves are always closed.



**Figure 3. Hadnot Point water treatment plant service area and water-distribution system**

### *Present-Day Operations*

System pressures range from about 55–68 psi (379–469 kPa) throughout the distribution systems. As topography is very flat, ranging from sea level to less than 40 ft (12 m), hydraulic heads range 140–160 ft (43–49 m) resulting in a very mild hydraulic gradient. There are nine elevated storage tanks in the Holcomb Boulevard and Hadnot Point WTP service areas (Figures 2 and 3). The range in water level fluctuation for the elevated storage tanks is small; generally 1–6 ft (0.3–2 m) according to March 2004 data (Table 1). Three of the elevated storage tanks—SM623, S2323, and SFC314—operate as controlling tanks. When demand causes water levels in these tanks to drop below a minimum water-level mark, high-lift pumps are turned on at the WTPs or at the Tarawa Terrace treated water reservoir to fill the controlling elevated storage tanks to a maximum water level. The pumps are then shut off (Table 1).

The average annual flow for 2004 for treated water at Holcomb Boulevard WTP was 0.803 MGD (35.2 L/s). Furthermore, an additional 0.658 MGD (28.8 L/s) of treated water from the Holcomb Boulevard WTP was delivered to the Tarawa Terrace ground storage reservoir. For the Hadnot Point WTP, the average annual flow for 2004 was 2.35 MGD (103.0 L/s). Average monthly flows for 2004 for the WTPs are listed in Table 2. These data represent delivered water from the WTPs to the distribution system. Because Camp Lejeune is a military installation, the base does not require or install water consumption meters on housing units. With the exception of base power plants, other consuming entities (e.g., car

washes, swimming pools, office buildings) are not metered either. Thus, quantifying the magnitude and direction of flows within the distribution system is not possible because of the absence of flow meters.

**Table 1. Elevated Storage Tank Identification, Elevations, and Water Levels\***

Storage Tank Parameter	Holcomb Boulevard Water Treatment Plant Area				
	Camp Johnson: SM623 <sup>+</sup>	Tarawa Terrace: STT40	Paradise Point: S2323 <sup>§</sup>	Berkeley Manor: S830	Midway Park: LCH4004
Elevation, Bottom of Tank, in ft (m)	82 <sup>‡</sup> (25) <sup>‡</sup>	141.7 (43.2)	120.3 (36.7)	127.5 (38.9)	129.9 (39.6)
Maximum Water Level, in ft (m)	25.4 (7.7)	31.9 (9.7)	31.0 (9.4)	32.4 (9.9)	30.1 (9.2)
Minimum Water Level, in ft (m)	21.7 (6.6)	26.1 (8.0)	27.6 (8.4)	30.0 (9.1)	25.9 (7.9)
Water Level-Difference, in ft (m)	3.7 (1.1)	5.8 (1.8)	3.4 (1.0)	2.4 (0.7)	4.2 (1.3)
Storage Tank Parameter	Hadnot Point Water Treatment Plant Area				French Creek: SFC314 <sup>‡</sup>
	S5	S29	Industrial Area: S1000		
Elevation, Bottom of Tank, in ft (m)	126.3 (38.5)	125.3 (38.2)	127.4 (38.8)	134.8 (41.1)	
Maximum Water Level, in ft (m)	28.4 (8.6)	28.6 (8.7)	29.2 (8.9)	25.0 (7.6)	
Minimum Water Level, in ft (m)	27.5 (8.4)	27.1 (8.3)	26.8 (8.2)	20.3 (6.2)	
Water Level-Difference, in ft (m)	0.9 (0.3)	1.5 (0.4)	2.4 (0.7)	4.7 (1.4)	

\*Data from Camp Lejeune water utility department, March 1–7, 2004

<sup>+</sup>Controlling tank for Tarawa Terrace treated water reservoir

<sup>§</sup>Controlling tank for Holcomb Boulevard WTP

<sup>‡</sup>Controlling tank for Handot Point WTP

With respect to water-quality parameters, all raw water is supplied from groundwater wells pumping from the Castle Hayne formation that underlies the base. Raw water concentrations of chloride and fluoride are 0.14 and 0.2 mg/L, respectively (B. T. Ashton, Camp Lejeune Environmental Management Division, electronic communication, April 6, 2004). The raw water is treated with chlorine and lime at the WTPs. As a consequence, treated water has a chloride concentration of 20 mg/L (B. T. Ashton, Camp Lejeune Environmental Management Division, electronic communication, March 31, 2004). The addition of lime causes the pH of the treated water to be high—about 8.5–9. Sodium fluoride (NaF) crystals are added to the treatment process using a gravity-feed saturator system to fluoridate the water. The concentration of fluoride in the distribution system and elevated storage tanks averages about 1 mg/L (D. E. Hill, Camp Lejeune water department, written communication, May 2004).

**Table 2. Average Monthly Flows of Treated Water, 2004\***

Month	From Holcomb Boulevard Water Treatment Plant		To Tarawa Terrace Reservoir <sup>†</sup>		From Hadnot Point Water Treatment Plant	
	MGD	L/s	MGD	L/s	MGD	L/s
January	0.824	36.1	0.728	31.9	2.570	112.6
February	0.739	32.4	0.842	36.9	2.518	110.3
March	0.699	30.6	0.761	33.3	2.431	106.5
April	0.767	33.6	0.724	31.7	2.283	100.0
May	0.889	38.9	0.788	34.5	2.334	102.2
June	0.859	37.6	0.722	31.6	2.431	106.5
July	0.784	34.4	0.655	28.7	2.371	103.9
August	0.840	36.8	0.613	26.9	2.400	105.1
September	0.954	41.8	0.401	17.6	2.202	96.5
October	0.807	35.4	0.547	24.0	2.226	97.5
November	0.732	32.1	0.568	24.9	2.285	100.1
December	0.736	32.3	0.541	23.7	2.153	94.3
Annual mean	0.803	35.2	0.658	28.8	2.350	103.0

\*Data from Camp Lejeune water department, S. J. Whited, electronic communication, January 31, 2005.

<sup>†</sup>Tarawa Terrace reservoir water is treated at the Holcomb Boulevard WTP; the sum of the Holcomb Boulevard and Tarawa Terrace flows is total delivered water from Holcomb Boulevard WTP.

### ***Field-Testing Activities***

ATSDR reviewed and analyzed hydraulic and water-quality data, system operations, and a water conservation study of the base (ECG, 1999). It then began a field-testing program, in cooperation with USMCB Camp Lejeune, to obtain data necessary to calibrate present-day water-distribution models to assist the epidemiologic study. As part of this effort, ATSDR has conducted tests in the Hadnot Point and Holcomb Boulevard WTP areas, including Tarawa Terrace and Camp Johnson. These tests are considered to be “preliminary tests” that provided ATSDR with initial data to begin preliminary model simulations. The preliminary data and model simulations will be used to assist with the planning and conduct of a detailed water-distribution system test of all areas during peak-demand season in summer 2005. In what follows, the preliminary field tests are briefly described. Photographs of some of the equipment used for the field tests are shown in Figure 4A–4D. Preliminary data are presented and discussed in the “Discussion of Results” section.

**Hadnot Point WTP area, May 2004.** This field test was conducted May 24–27 and consisted of three activities: (1) injecting liquid calcium chloride (CaCl<sub>2</sub>), 35% by weight, into the transmission main on the distribution system side of the WTP to achieve an elevated conductance and chloride concentration, and recording conductivity and chloride concentration using continuous recording water-quality monitoring data loggers, (2) injecting a sodium fluoride solution into the transmission main to achieve an elevated fluoride concentration (before the test, the WTP fluoride was shut off so that fluoride concentrations in the distribution system pipelines approached background levels of about 0.2 mg/L), and (3) monitoring distribution system pressures with continuous recording data loggers attached to selected hydrants. In addition to continuously recording tracer concentrations and conductivity, grab samples were collected for quality assurance and quality control (QA/QC) purposes. Samples were analyzed at the Hadnot Point WTP by ATSDR staff and then also shipped to the Federal Occupational Health (FOH) laboratory in Chicago, Illinois, for

analysis. Twenty-seven hydrants were selected in the Hadnot Point area as monitoring locations. For monitoring conductivity and chloride and fluoride concentrations nine hydrants were equipped with the Horiba W-23XD dual probe ion detector (Figure 4A). For monitoring conductivity, nine hydrants were equipped with the Horiba W-21XD single probe ion detector (Figure 4B), thus providing a total of 18 monitoring locations for continuously recording conductivity data. For pressure measurements, nine hydrants were equipped with continuous recording Dixon PR300 pressure data loggers (Figure 4C).

**Calcium chloride solution and injection.** The quantity and injection rate of  $\text{CaCl}_2$  was based on: (1) using a 35% by weight liquid  $\text{CaCl}_2$  solution, (2) the average flow rate of delivered water from the WTP for May 2002, and (3) assuring that the chloride concentration in the distribution system—resulting from the injection of  $\text{CaCl}_2$ —would not exceed the U.S. Environmental Protection Agency’s secondary maximum contaminant level (MCL) for chloride of 250 mg/L. The average flow delivered by the Hadnot Point WTP for May 2002 was 3.0 MGD (131.4 L/s)—a typical year based on discussions with Camp Lejeune water utility staff. A flow-paced pump capable of injecting  $\text{CaCl}_2$  at a rate of 1.0 gpm ( $6.3 \times 10^{-2}$  L/s) with a main transmission line pressure of 55 psi (379 kPa) was used. Using this type of injection pump assured that if the flow rate of delivered water changed based on demand, the  $\text{CaCl}_2$  injection rate would also change to maintain a near-constant concentration of the mixed  $\text{CaCl}_2$  and treated water. A background chloride concentration of 20 mg/L and complete mixing within a short distance downstream from the injection point were also assumed. Thus, the maximum chloride concentration in the distribution system was predicted to be 164 mg/L—well below the MCL of 250 mg/L. Nine, 55-gal (208 L) drums of  $\text{CaCl}_2$  were pumped into a 525-gal (1,987 L) plastic holding tank. At 0800 hours on May 25, the  $\text{CaCl}_2$  was injected into the main transmission line for 6 continuous hours.

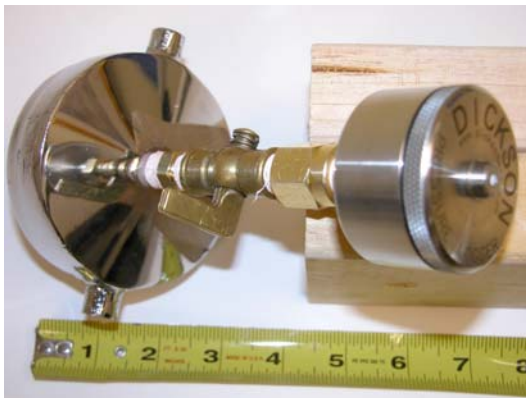
**Sodium fluoride solution and injection.** The source of the fluoride used for the tracer injection was the NaF crystals (Solvay Fluoride) used at the Hadnot Point WTP. It comes in 50-lb (22.7 kg) bags. Based on the solubility of NaF of 42 g/L, this resulted in an equivalent of 19 g/L of F. To assure the public’s health and safety, an upper limit for the fluoride concentration in the distribution system was set at 2.0 mg/L using a background fluoride concentration of 0.2 mg/L and assuming complete mixing within a short distance downstream from the injection point. The same flow and injection rates previously described for the  $\text{CaCl}_2$  injection were used for the NaF injection. On the basis of mass balance calculations, 36 lb (16.4 kg) of NaF were mixed with 500 gal (1,893 L) of treated water in a 525-gal (1,987 L) plastic holding tank. Experience has shown that even when a solution is continuously stirred during an injection test, some of the solids still settle to the bottom of the tank and will not dissolve into the tracer solution (Boccelli et al., 2003). To compensate for this, the entire 50-lb (22.7 kg) bag of NaF was mixed with the 500 gal (1,893 L) of water in the tank. The treated water used to mix with the NaF crystals had a background fluoride concentration of 0.2 mg/L as the WTP fluoride was shut off the previous week in preparation for the tracer test. At 0800 hours on May 26, the NaF solution was injected into the main transmission line. Although the duration of the NaF injection was initially planned to be 6 hours long, at 1148 hours, the injection pump broke. The pump was subsequently repaired and at 1315 the injection of NaF solution was resumed. The injection was terminated at 1545 hours. Thus, unlike the  $\text{CaCl}_2$  tracer test that was characterized by one continuous 6-hour long injection, the NaF tracer test was characterized by two pulses of NaF solution—the first pulse having a duration of 3 hours 48 minutes and the second pulse having a duration of 2 hours 30 minutes.



(A)



(B)



(C)



(D)

**Figure 4. Photographs of selected field test equipment: (A) Horiba W-23XD dual probe ion detector inside flow cell, (B) Horiba W-21XD single probe ion detector inside flow cell, (C) Dixon PR300 continuous recording pressure logger mounted on brass shutoff valve and hydrant adapter cap, and (D) Plant PRO HFD hydrant flow tester with diffuser**

**Holcomb Boulevard and Hadnot Point WTP areas, August 2004.** This field test was conducted August 25–27. It consisted of two activities: (1) testing different sections of pipelines of varying diameters and material types to collect hydraulic data for calculating roughness coefficients (Hazen-Williams C-factor data), and (2) applying an innovative



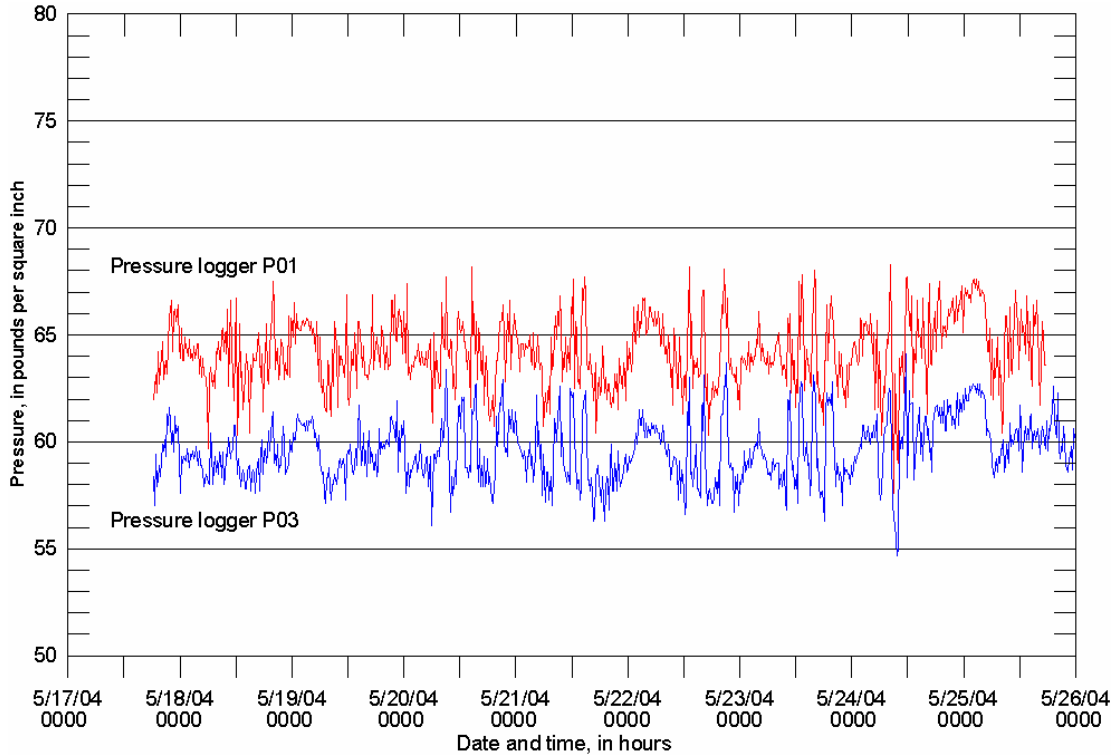
approach for fire-flow testing (for model calibration purposes) using continuous recording pressure monitors at several fire hydrants simultaneously while different combinations of hydrants were flowed. To continuously record pressure data, the Dixon PR300 pressure data logger was used (Figure 4C). To record flow and pressure from flowed hydrants, the Plant PRO HFD hydrant flow tester with a diffuser was used (Figure 4D). C-factor tests were conducted at eight locations characterized by three different pipe materials (cast iron, polyvinyl chloride (PVC), and asbestos cement). Pipeline diameters ranged from 6–12 inches (15–30 cm). Tested pipe lengths ranged from 700–1,672 ft (213–510 m) and flows ranged from 564–1,603 gpm (35.6–67.1 L/s). Fire flow tests were conducted at 12 locations characterized by three different pipe materials (cast iron, polyvinyl chloride (PVC), and asbestos cement). Pipeline diameters ranged from 4–12 inches (10–30 cm). Tested pipe lengths ranged from 236–1,620 ft (72–494 m) and flows ranged from 773–1,120 gpm (48.8–70.7 L/s).

**Holcomb Boulevard WTP, September–October 2004.** This field test was conducted September 22–October 12. It consisted of monitoring fluoride decay and re-injection in the Holcomb Boulevard WTP area (including Tarawa Terrace and Camp Johnson). The purpose of this preliminary test was to (1) estimate travel time between points in the distribution system by shutting off and then restarting fluoride at the WTP, (2) to record the fill and draw characteristics at the controlling elevated storage tanks (S2323 and SM623 in Figure 2), (3) to record the sequence of when distribution-system water (with its fluoride concentration) was filling the tanks and when storage tank water (with its fluoride concentration) was being supplied to the distribution system, and (4) to conduct (QA/QC) tests on the fluoride sensors contained in the continuous recording dual probe data loggers (Figure 4C). Nine locations in the distribution system were equipped with the Horiba W-23XD continuous recording, dual probe ion detector data logger (Figure 2). Monitoring locations included the main transmission line from the WTP to the distribution system (F01 in Figure 2), the Tarawa Terrace treated water reservoir (F02), two controlling elevated storage tanks (F08 and F09), and five hydrants located throughout the housing areas (F03, F04, F05, F06, and F07). The fluoride at the Holcomb Boulevard WTP was shut off at 1600 hours on September 22. A background concentration of about 0.2 mg/L in the distribution system was reached by September 28. At 1200 hours on September 29, the fluoride was turned back on at the WTP and the test continued until loggers were removed and data downloaded on October 12. In addition to the continuous recording data loggers, split grab sample analyses were conducted for QA/QC purposes. Nine rounds of water samples were collected at each monitoring location during the test. For each round, the Holcomb Boulevard WTP water-quality lab analyzed 25 mL of the grab sample water and the FOH laboratory analyzed the remaining 225 mL of water.

### ***Discussion of Results***

Recorded pressure data confirmed that pressure throughout the Hadnot Point WTP area ranges from 55–68 psi (379–469 kPa), with a mean of about 60 psi (414 kPa). Other parts of the distribution system (Holcomb Boulevard WTP, Tarawa Terrace, etc.) are operated in a similar manner and have been operated the same way historically (1968–85). Figure 5 shows data from two continuous recording pressure data loggers recorded at 15-minute intervals during the May 2004 test. Logger P01 was located in the northwesternmost part of Hadnot Point WTP area (Figure 3). Logger P03 was located adjacent to the WTP. Because of the nearly constant pressure, flat topography, and resulting small hydraulic

gradient (about  $1 \times 10^{-4}$ ), as previously discussed, it would be extremely difficult to achieve a unique hydraulic calibration without using water-quality data and tracer-test results.

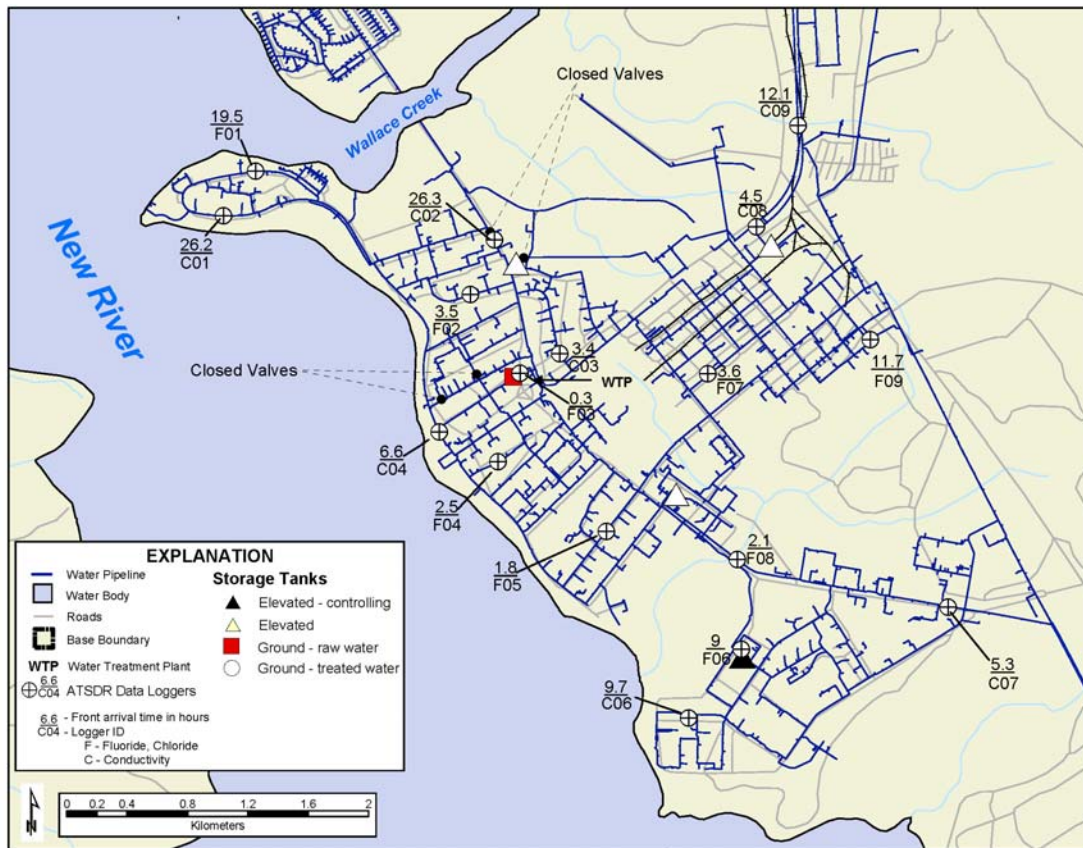


**Figure 5. Graphs showing recorded pressure data in the Hadnot Point WTP area, May18–25, 2004 (refer to Figure 3 for hydrant locations)**

Results from the chloride injection provide data for quantifying arrival times of the tracer at different locations throughout the Hadnot Point WTP area. Of special interest are the extremely long arrival times—in excess of 16 hours—in the northwestern part of the of the Hadnot Point WTP area (Figure 6, loggers C01, C02, and F01). Additionally comparing arrival times of the  $\text{CaCl}_2$  tracer at logger location C04 with arrival times at loggers F04, C05, and F02, led investigators to suspect that there may have been undocumented closed valves in the distribution system. Post-test field verification by water utility staff confirmed the locations of closed valves, as indicated by the “•” symbol in Figure 6. Further analysis of the arrival time data shown in Figure 6 indicate that from the location of logger F08, the tracer travels east to logger C07 rather than south to loggers F06 and C06. The reason is that arrival time of the tracer at logger C07 is about 3 hours after arrival at logger F08, whereas arrival time of the tracer at loggers F06 and C06 is about 7 hours after the tracer arrives at logger F08.

Using the hydraulic data gathered during the August 2004 field-test activities, Hazen-Williams C-factors were computed for eight sections of tested pipelines (Table 3). Results presented in Table 3 show good agreement between the C-factor values determined from the field-testing activities and those published in the literature (Walski et al., 2003). The mean of the two C-factor tests conducted on PVC type pipes is 137, compared with a literature value of 147. The mean of the four C-factor tests conducted on cast iron pipes is 102, compared with literature values of 97–102. In conducting these tests, both continuous recording pressure data loggers (Dixon PR300, Figure 4C) and hand-held pressure gauges were used to

record pressures. The continuous recording pressure data loggers were set to record pressure at 1-minute intervals.



**Figure 6. Arrival times of the calcium chloride tracer at monitoring locations, Hadnot Point WTP area, May 25, 2004**

As discussed previously in the section on “Field-Testing Activities,” the preliminary test conducted in the Holcomb Boulevard WTP area, during September–October 2004, was conducted by shutting off and then restarting the fluoride used at the Holcomb Boulevard WTP. The test was also used to conduct QA/QC on the fluoride sensors used in the continuous recording water-quality data loggers (Figure 4A). Results from the test for six selected locations (F01, F02, F03, F04, F08, and F09) are presented in Figure 7.

Logger F01 was located on the main transmission line going from the Holcomb Boulevard WTP to the distribution system (Figure 2). It can be considered as the logger that represents the source conditions for fluoride in the Holcomb Boulevard WTP service area. Agreement is very good between the continuous recording data logger (solid line) and QA/QC grab samples analyzed at the WTP water-quality laboratory and the FOH water-quality laboratory.

Logger F02 was attached to the main transmission line distributing water from the Tarawa Terrace treated water reservoir (Figure 2). The decrease and increase in fluoride concentration is significantly attenuated compared with the source logger (F01) because of the large volume of water that is contained in the reservoir. Additionally, with this logger, two fluoride sensors were used for QA/QC purposes. Comparing the two fluoride sensors

(ion2 and ion3 on the graph of F02) with grab sample data indicates very consistent results. However, after about 14 days, the logger data appear to show some “drift” in the logger calibration with respect to the grab sample data.

**Table 3. Hazen-Williams C-factor Values for Holcomb Boulevard and Hadnot Point Water Treatment Plant Service Areas, August 2004**

Test ID	Pipe Length, ft (m)	Nominal Diameter, in.	Flow, gpm	Pipe Material	Computed C-factor	Reference C-factor*
CF-H01	848	12	1,603	PVC	161	147
CF-H02	1,181	8	590	Cast iron	102	97–102
CF-H03	793	6	564	Cast iron	93	97–102
CF-H04	1,558	8	715	Cast iron	122	97–102
CF-H05	700	10	947	Cast iron	77	97–102
CF-H06	1,416	10	835	PVC	113	147
CF-H07	1,167	8	835	Cast iron	117	97–102
CF-H08	1,672	10	920	Asbestos cement	148	150

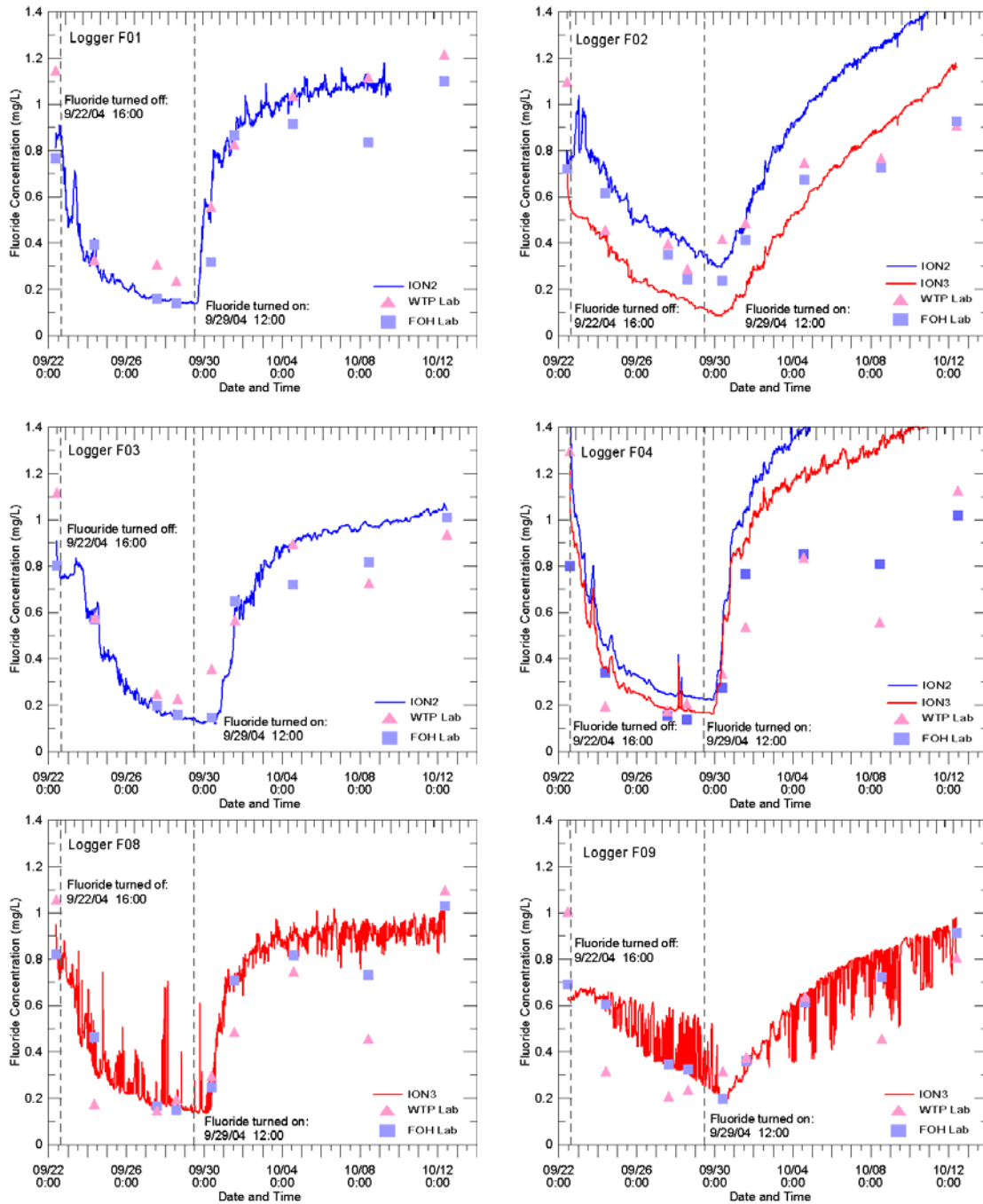
\*Data from Walski et al. (2003)

1 in. = 2.52 cm; 1 ft = 0.3048 m; 1 gpm = 0.6309 L/s

Loggers F03 and F04 were attached to hydrants located in family housing areas (Figure 2). Data from both loggers are in good agreement with grab sample data and both show logger “drift” with respect to calibration after about 10–12 days. Both loggers also show nearly identical pulses as the source logger (F01) indicating that there is probably little mixing or traveling through complex paths from the WTP to these housing areas.

Loggers F08 and F09 were monitoring elevated storage tanks. Both of these tanks are controlling tanks, so that the water level in the tank is allowed to fluctuate as demand varies (see previous discussion in section on “Present-Day Operation”). The graphs for loggers F08 and F09 clearly show the draw and fill cycles of the tanks. The graph for logger F08 shows that the fluoride concentration in the distribution system reached a near background level of about 0.2 mg/L on September 28. Even so, the elevated storage tank still has water with a fluoride concentration of about 0.8 mg/L. Data from logger F09 clearly show a more attenuated pattern than the data for logger F08.

Data from all the tests described herein are still being analyzed. These data are being used to assist with model calibration and to design a comprehensive field test that will take place during summer 2005. The hydraulic and water-quality tests to date have yielded data that investigators can use to interpret hydraulic characteristics and water-quality dynamics within the distribution systems serving family housing areas of Camp Lejeune. The pressure data shown in Figure 5 and the C-factor data listed in Table 2 represent the hydraulic characteristics of the distribution systems. Figure 6 shows arrival time data. Figure 7 presents fluoride concentration data showing the fill and draw action of elevated storage tanks. These represent water-quality data that will be used to gain insight into residence and travel times of water-distribution system dynamics. Thus, conducting field tests that yield both hydraulic and water-quality parameter data is essential to understanding parameter uncertainty and variability. The data also are essential for developing calibrated hydraulic and water-quality present-day models at Camp Lejeune to assist the epidemiologic study.



**Figure 7. Graphs of fluoride concentration at logger locations F01, F02, F03, F04, F08, and F09 in the Holcomb Boulevard water treatment plant service area, September–October 2004 (refer to Figure 2 for logger locations)**

### *Summary*

This study presents results from preliminary field-test activities used to gather hydraulic and water-quality data at USMCB Camp Lejeune, North Carolina. Field tests to date have included: (a) recording system pressures and storage tank water levels, and (b)

conducting C-factor, fire-flow, tracer, and travel time tests. The test data are being used to assist with hydraulic and water-quality model calibration. They also are being used to plan and carry out a more refined, detailed field test of water-distribution systems serving military base housing. These activities will assist in providing much needed model parameter data for calibrating models of the present-day water-distribution system. The present-day models are needed as a first step in reconstructing historical operations during the period 1968–1985, as part of an ongoing epidemiologic study of childhood diseases at Camp Lejeune.

### ***Acknowledgment***

The authors acknowledge the staff of the Camp Lejeune Environmental Management Division and water utility department who assisted with data requests and logistics for conducting the field tests described herein. Authors also acknowledge staff from ATSDR, National Center for Environmental Health, U.S. Geological Survey, and R.E. Faye & Associates for assistance with field testing and data collection activities.

### ***Disclaimer***

Use of trade names and commercial sources is for identification only and does not imply endorsement by the Agency for Toxic Substances and Disease Registry, the U.S. Department of Health and Human Services, the Georgia Institute of Technology, or the Oak Ridge Institute for Science and Education.

### ***References***

- Agency for Toxic Substances and Disease Registry (ATSDR). (1990). *Public health assessment for ABC One Hour Cleaners, Jacksonville, Onslow County, North Carolina*, U.S. Department of Health and Human Services, Atlanta, Georgia.
- Agency for Toxic Substances and Disease Registry (ATSDR). (1997). *Public health assessment for U.S. Marine Corps Base at Camp Lejeune, Military Reservation, Camp Lejeune, Onslow County, North Carolina*, U.S. Department of Health and Human Services, Atlanta, Georgia.
- Agency for Toxic Substances and Disease Registry (ATSDR). (1998). *Volatile organic compounds in drinking water and adverse pregnancy outcomes, United States Marine Corps Base, Camp Lejeune*, U.S. Department of Health and Human Services, Atlanta, Georgia.
- Boccelli, D. L., Shang, F., Uber, J. G., Orcevic, A., Moll, D., Hooper, S., Maslia, M., Sautner, J., Blount, B., and Cardinali, F. (2004) "Tracer tests for network model calibration." *Proceedings of the 2004 World Water and Environmental Resources Congress*, American Society of Civil Engineers, [CD ROM document], Salt Lake City, UT, June 27–July 1.
- ECG, Inc. (1999). *Marine Corps Base Camp Lejeune and Marine Corps Air Station, New River Water Conservation Analysis*, Vienna, Virginia.
- Walski, T. M., Chase, D. V., Savic, D. A., Grayman, W. M., Beckwith, S., and Koelle, E. (2003). *Advanced water distribution modeling and management*, Haestad Press, Waterbury, Connecticut.