Prepared in cooperation with the
Southern Division Naval Facilities Engineering Command

Magnitude and Extent of Arsenic and Thallium Concentrations in Ground Water and Sediments at the Charleston Naval Complex, North Charleston, South Carolina, 1994-99

U.S. Geological Survey
Water-Resources Investigations Report 02-4226

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

Magnitude and Extent of Arsenic and Thallium Concentrations in Ground Water and Sediments at the Charleston Naval Complex, North Charleston, South Carolina, 1994–99

By June E. Mirecki and W. Fred Falls

U.S. GEOLOGICAL SURVEY

Water-Resources Investigations Report 02–4226

Prepared in cooperation with the

SOUTHERN DIVISION NAVAL FACILITIES ENGINEERING COMMAND

U.S. DEPARTMENT OF THE INTERIOR
MARCH 3, 1849

Columbia, South Carolina
2002

U.S. DEPARTMENT OF THE INTERIOR
GALE A. NORTON, Secretary

U.S. GEOLOGICAL SURVEY
CHARLES G. GROAT, Director

For additional information write to:

District Chief
U.S. Geological Survey
720 Gracern Road, Suite 129
Columbia, SC 29210-7651

dc_sc@usgs.gov

Copies of this report can be purchased from:

U.S. Geological Survey
Branch of Information Services
Box 25286, Federal Center
Denver, CO 80225-0286

1-888-ASK-USGS

Information about U.S. Geological Survey programs in South Carolina is available on the Internet at http://sc.water.usgs.gov.

CONTENTS

PLATES

FIGURES

TABLES

CONVERSION FACTORS, TEMPERATURE, WATER-QUALITY UNITS, and ABBREVIATIONS

Multiply	**by**	**To obtain**
	Length	
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
	Area	
acre	0.4047	hectare (ha)
	Mass	
ounce (oz)	28.35	gram (g)

***Temperature*:** Water temperature is given in degrees Celsius (°C), which can be converted to degrees Fahrenheit (°F) as follows:

$$°F = (°C \times 1.8) + 32$$

***Water-quality units*:**

Liter (L) is a unit of liquid volume equal to approximately 1.057 quarts. 1,000 milliliters (mL) is equivalent to 1 liter.

Milligram per liter (mg/L) or microgram per liter (µg/L)**:** Milligram per liter is a unit expressing the concentration of a chemical constituent as weight (milligram of solute per unit volume (liter) of water). 1,000 micrograms per liter is equivalent to 1 milligram per liter. For concentrations less than 7,000 mg/L, the numerical value is the same as for concentration in parts per million.

Milligram per kilogram (mg/kg) is a unit expressing the concentration of a chemical constituent as weight (milligram of solute per unit volume (kilogram) of soil or sediment). The numerical value is the same as for concentration in parts per million.

Mole of a substance is its formula weight expressed in grams.

***Abbreviations*:**

AOC	Area of concern
As(III)	Arsenite
As(V)	Arsenate
CERCLA	Comprehensive Environmental Restoration, Compensation, and Liability Act
CNC	Charleston Naval Complex
GFAAS	Graphite furnace atomic absorption spectrophotometry
GIS	Geographic information system
ICP-AES	Inductively coupled plasma-atomic emission spectroscopy
ICP-MS	Inductively coupled plasma-mass spectroscopy
MCL	Maximum contaminant level
NPL	National priority list
PEL	Probable-effects level
RCRA	Resource Conservation and Recovery Act
>	Greater than
<	Less than
SWMU	Solid-waste management unit
TEL	Theshold-effects level
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey

Magnitude and Extent of Arsenic and Thallium Concentrations in Ground Water and Sediments at the Charleston Naval Complex, North Charleston, South Carolina, 1994–99

By June E. Mirecki and W. Fred Falls

ABSTRACT

Water-quality samples were collected quarterly during 1994–99 from 604 wells screened in the surficial aquifer system beneath the Charleston Naval Complex, North Charleston, South Carolina. Arsenic and thallium were selected for analysis because concentrations of these metals in some wells consistently exceeded the established (2001) drinking-water maximum contaminant levels of 10 and 2 micrograms per liter, respectively. The analysis was conducted to determine the magnitude and spatial distribution of arsenic and thallium in ground water at the Charleston Naval Complex and to quantify arsenic and thallium concentrations in a dated sediment core from Shipyard Creek marsh near the southern boundary of the Naval Complex.

The surficial aquifer system beneath the Charleston Naval Complex consists of an unconfined upper surficial aquifer and a confined lower surficial aquifer. Hydraulic connection between the two aquifers is limited or nonexistent throughout the system at the Naval Complex. The Charleston Naval Complex is divided into nine operational units designated as zones A through I. Arsenic and thallium concentration data were compiled and interpreted for the two surficial aquifers within each zone.

Mean arsenic (n=603) and thallium (n=604) concentrations were calculated for water samples from each well screened in the upper and lower surficial aquifers. In the upper surficial aquifer, mean arsenic concentrations ranged from 0.9 to 339 micrograms per liter and exceeded 10 micrograms per liter in 29 percent of the wells. In the lower surficial aquifer, mean arsenic concentrations ranged from 1.0 to 97.4 micrograms per liter and exceeded 10 micrograms per liter in 23 percent of the wells. The greatest number of water samples with mean arsenic concentrations exceeding 10 micrograms per liter were collected from wells in the upper surficial aquifer at zone E in the northwestern part of the study area.

Well clusters, defined as three or more wells in a solid-waste management unit or area of concern, where the mean arsenic concentration exceeded 10 micrograms per liter, were identified in association with 12 sites in the upper surficial aquifer—solid-waste management unit 039 (a drum-storage area) in zone A; solid-waste management units 044 (coal-storage area) and 047 (burning dump) in zone C; solid-waste management unit 065 (lead-storage area) and area of concern 556 (dry docks 3 and 4) in zone E; areas of concern 609 (building 1346 gas station) and 613 (locomotive shop) in zone F; solid-waste management units 006 (public works storage yard) and 008 (oil sludge pit), and area of concern 709 (fuel-delivery system wells 12, 13, and 14) in zone G; and solid-waste management units 009 (closed landfill) and 196 (south landfill) in zone H. One well cluster was identified in the lower surficial aquifer in association with solid-waste management unit 009 (closed landfill) in zone H.

Mean thallium concentrations in water from all wells ranged from less than 1.6 to 32.6 micrograms per liter in water samples from the upper surficial aquifer, and from less than 1.6 to 67.7 micrograms per liter in water samples from the lower surficial aquifer. Mean thallium concentrations equal to or greater than 10 micrograms per liter were present in water samples from 21 of 604 wells (3.5 percent). Of the 21 wells, 14 wells were located at solid-waste management unit 009 (closed landfill) in zone H near Shipyard Creek, 8 wells in the upper aquifer, and 6 wells in the lower

aquifer. One well cluster where thallium exceeded 10 micrograms per liter was identified in association with solid-waste management unit 009 (closed landfill) in the upper surficial aquifer.

Mean arsenic and thallium concentrations in water were calculated for all wells screened in one aquifer and located in a single zone, and are referred to as zone mean concentration in this report. Zone mean arsenic concentrations in all nine zones ranged from 3.2 to 18 micrograms per liter in water samples from the upper surficial aquifer and from 2.7 to 22 micrograms per liter in water samples from the lower surficial aquifer. Zone mean thallium concentrations in all nine zones ranged from 3.2 to 13 micrograms per liter in water samples from the upper surficial aquifer and from 3.2 to 14 micrograms per liter in water samples from the lower surficial aquifer.

Ground-water samples rarely had elevated (equal to or greater than 10 micrograms per liter) concentrations of both arsenic and thallium. Water samples had coincident elevated arsenic and thallium concentrations in 10 wells in zone H, 1 well in zone A, and 1 well in zone B.

Sediment quality at Shipyard Creek marsh was investigated by collecting an 11.8-foot-long sediment core (SYC-1) adjacent to zone I. The mean arsenic concentration in sediment samples from SYC-1 (n=160) was 3.05 milligrams per kilogram plus or minus 0.92. The mean arsenic concentration and standard deviation calculated for SYC-1 sediment samples fall within the standard error for the background mean arsenic concentration reported for South Carolina sediments (1.5 milligrams per kilogram plus or minus 2.7). All but one sample (core depth =50 inches) was less than the threshold-effects level of 7.24 milligrams per kilogram. Acid extracts of the sediment samples were analyzed for thallium concentration, but none were detected. These data indicate no obvious change in arsenic or thallium concentrations with depth in the core.

INTRODUCTION

Arsenic and thallium occur naturally as trace constituents in different minerals, including sedimentary pyrite, sulfide ores, and iron oxides. These trace elements can be found in sediment and leached from sediment and minerals into ground water. In ground water associated with these natural mineral sources, arsenic and thallium concentrations are generally below 3 and 1 µg/L, respectively (U.S. Environmental Protection agency, 1980; Agency for Toxic Substances and Disease Registry, 1992, 2000; Focazio and others, 2000).

Anthropogenic sources also can release arsenic and thallium to ground water. Arsenic is an active ingredient in some rodenticide, insecticide, and pesticide formulations (Eisler, 1988; Azcue and Nriagu, 1994), particularly in developing countries. Analysis of leachate from pre-1910 graveyards indicates high arsenic concentrations (Fetter, 1999). Arsenic and thallium are enriched in flue particulates formed during pyrite roasting for sulfuric acid and fertilizer manufacture (Holmes, 1870) or during smelter operation. Thallium was used as a pesticide and rodenticide prior to 1975. Presently (2002), thallium is used as a myocardial-imaging agent, an additive during low-temperature glass manufacture (Lide, 1995), and in semiconductors (Nriagu, 1998).

The U.S. Environmental Protection Agency (USEPA) regulates the levels of arsenic and thallium in drinking water because these trace elements are known or suspected carcinogens (Lide, 1995), and they exhibit toxic effects at low concentrations in humans (Agency for Toxic Substances and Disease Registry, 1992; 2000). The USEPA established primary standards for contaminants in drinking water and regulations to ensure compliance with these standards in the National Primary Drinking Water Regulations (U.S. Environmental Protection Agency, 2000a). A primary standard is the highest concentration of a contaminant that is allowed in drinking water and is called the maximum contaminant level (MCL). The MCLs in drinking water are 2 µg/L for thallium and 10 µg/L for arsenic (U.S. Environmental Protection Agency, 2000a, 2001). Both trace elements are mobile in subsurface environments because they exist either as inorganic cations or complexed oxyanions that can migrate in ground water over a wide range of pH and redox conditions.

The MCL for arsenic has been the subject of some controversy and revision over the past 6 years. In the 1996 amendments to the Safe Drinking Water Act, the USEPA was required to revise the MCL of 50 µg/L for arsenic (U.S. Environmental Protection Agency, 1996). A 1999 report published by the National Research Council of the National Academy of Science and commissioned by the USEPA concluded that the MCL for arsenic was too high and should be set at a lower level for public-health protection (National Research Council, 1999). In 2000, the USEPA proposed four potential MCLs of 3, 5, 10, and 20 µg/L (U.S. Environmental Protection Agency, 2000b). In January 2001, the USEPA published the final ruling that established the arsenic MCL of 10 µg/L (U.S. Environmental Protection Agency, 2001).

The magnitude of ground-water contaminant concentrations at military installations and industrial sites is evaluated in the context of regulatory MCLs (U.S. Environmental Protection Agency, 2000a). Because trace elements in ground water can be attributed to both anthropogenic and natural sources, the determination of a "natural background concentration" is useful, particularly in areas where no point source or observable process is present to explain environmental concentrations greater than the MCL. The natural background concentration of arsenic in ground water is best estimated by chemical analyses from the source aquifer and geologic setting, where no anthropogenic input is suspected.

The magnitude of sediment contaminant concentrations at military installations and industrial sites is evaluated by using several nonregulatory guidelines, because Federal MCLs are not applicable to sediments and soils, and because coastal sediment and soil composition and provenance vary widely. Sediment-quality guidelines allow for the assessment of sediment with respect to level-of-concern concentrations. The USEPA nonregulatory guidelines for arsenic in sediment include a threshold-effects level (TEL) and a probable-effects level (PEL) of 7.24 and 41.6 mg/kg, respectively (U.S. Environmental Protection Agency, 1998). Toxic effects rarely occur at concentrations below the TEL, occasionally occur at concentrations between the TEL and the PEL, and frequently occur at concentrations above the PEL. The PEL and the TEL are nonregulatory guidelines and, as such, are intended for use as screening tools. Another approach is to statistically compare the range of sedimentary trace-element concentrations measured at a contaminated site to independent measurements of trace-element concentrations in uncontaminated (natural background) soils and sediment from a similar, local geologic setting.

If concentrations for a specific metal or contaminant in the sediment at a site are above background levels or above the TEL or the PEL, then a risk-based approach is routinely used to define maximum acceptable trace-element concentrations in sediments and soils and to support decisions during Comprehensive Environmental Restoration, Compensation, and Liability Act (CERCLA or Superfund) and Resource Conservation and Recovery Act (RCRA) investigations. These investigations define the maximum trace-element concentrations that are allowed in sediments and soils, depending on final site use (industrial or residential, for example).

Arsenic and thallium concentrations were identified as contaminants of concern in ground water and sediments at the Charleston Naval Complex (CNC; fig. 1) in North Charleston, South Carolina, during quarterly RCRA sampling conducted from 1994 through 1999 (EnSafe/Allen & Hoshall, Inc., 2000). Naval operations ceased at the CNC in April 1996. Since then, the site has been occupied by a variety of commercial, State, and Federal entities. Successful closure of this site involves the characterization of all potential on-site sources of contamination and remediation of contaminated sites, such as solid-waste management units (SWMUs) and areas of concern (AOCs) that represent a risk to human health and the environment. A determination of the magnitude and extent of arsenic and thallium concentrations in ground water and sediments at the CNC will contribute to the successful closure of this facility by the U.S. Navy.

Purpose and Scope

This report presents the results of a study by the U.S. Geological Survey (USGS) in cooperation with the Southern Division Naval Facilities Engineering Command to analyze the magnitude and geographic extent of arsenic and thallium concentrations in ground water at the CNC, North Charleston, S.C. Mean arsenic ($n=603$) and thallium ($n=604$) concentrations were calculated by using water samples collected from wells screened in either the unconfined upper surficial aquifer or the confined lower surficial aquifer at the CNC (plates 1, 2; app. 1). The magnitude of arsenic and thallium concentrations in ground water was evaluated by statistically comparing all CNC ground-water data or subsets of ground-water data collected during previous investigations (C. Vernoy, EnSafe/Allen & Hoshall, Inc., written commun., 2000). The geographic extent of arsenic and thallium in ground water was evaluated qualitatively by using a geographic information system (GIS) to show the spatial distribution of mean concentrations, so that clusters of mean concentrations that exceeded the MCL could be identified and their relation to potential point sources (SWMUs or AOCs) could be discussed.

Arsenic and thallium concentrations were analyzed in a dated sediment core (SYC-1, fig. 1) collected from Shipyard Creek marsh to determine if sedimentary arsenic and thallium concentrations derived from the CNC and adjacent sites on the creek increased through time from about 1800 to 2001.

Site History

The U.S. Naval Station at Charleston was chartered in August 1902 and occupied lands of the former

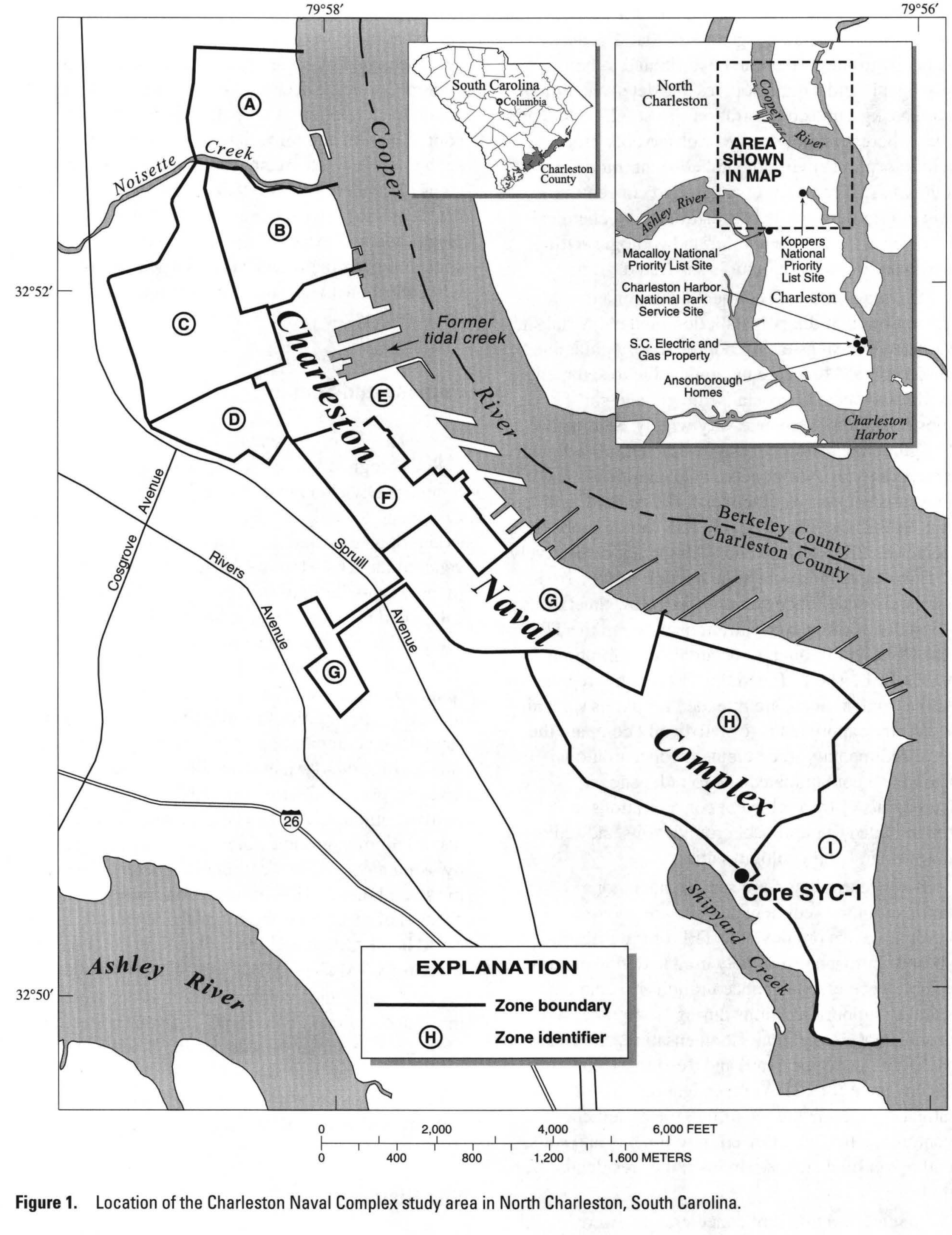


Figure 1. Location of the Charleston Naval Complex study area in North Charleston, South Carolina.

Marshlands, Mon Repos, and Retreat Plantations (McNeil, 1985). In 1907, the first dry dock on the Cooper River was constructed for repairs of boats and submarines. A second dry dock on the Cooper River was begun during World War I but was never completed. A new shipyard with a third dry dock was constructed on the Cooper River during World War II and was accompanied by rapid growth of the facility. Base operations expanded toward the confluence of Shipyard Creek and the Cooper River with the addition of facilities to support the construction of destroyer escorts and landing craft (plate 1). After World War II, the U.S. Naval Station and Naval Yard at Charleston were combined and renamed the U.S. Naval Base at Charleston, and the mission changed to focus on fleet repairs, restoration, and decommissioning of ships and submarines. The first nuclear submarine overhaul occurred in 1963 along with construction of a fifth dry dock. Construction and restoration of nuclear submarines remained the primary mission of the CNC until its operation ceased in 1996 (McNeil, 1985; Ecology & Environment, Inc., 1995).

In the vicinity of the CNC, arsenic concentrations may be elevated locally as well as regionally as a result of historical industrial activity or geologic conditions. Approximately nine facilities produced fertilizer at or near the CNC from the time of the Civil War to 1970 (Ecology & Environment, Inc., 1995). As part of the fertilizer production process, pyrite-rich rock was roasted to form sulfuric acid. Many of these former facilities are now under consideration as CERCLA sites. Waste-disposal practices, surface runoff, and dredged material disposal may have caused elevated arsenic concentrations locally in the surficial aquifer and sediments. Arsenic concentrations in ground water may be elevated naturally as a result of the interaction of ground water with phosphorite deposits at depths ranging from 20 to 50 ft below land surface. Values for arsenic concentrations in South Carolina phosphorite, according to the literature, range from 9 to 89 mg/kg (National Academy of Sciences, 1977).

A point source for chromium and other metals exists in the vicinity of Shipyard Creek (Kartman, 1999). A previous investigation revealed an increase in sediment-bound chromium present in post-1940 sediments recovered from core SYC-1 from Shipyard Creek marsh (Mirecki and Delong, 1997).

Acknowledgments

The authors extend their appreciation to M. Anthony Hunt, Southern Division Naval Facilities Engineering Command, for support of this project. G. Todd Haverkost and Charles A. Vernoy, both of EnSafe Inc. (formerly EnSafe/Allen & Hoshall, Inc.), kindly provided access to RCRA water-quality and GIS databases.

HYDROGEOLOGY OF THE STUDY AREA

The study area is located in North Charleston, S.C., at the confluence of the Cooper River and Shipyard Creek (fig. 1). The tidally influenced Noisette Creek flows into the Cooper River near the northern boundary of the site. The CNC occupies 1,383 acres, approximately one-half of which previously was salt marsh that has been covered progressively by deposits of dredged material (silty mud from Shipyard Creek and the Cooper River), calcareous silt of the Ashley Formation, and construction rubble and debris as the CNC area and operations expanded. The CNC is divided into nine conterminous zones (A through I). Each zone contains sites or features that were related to military activities or production processes, designated as SWMUs or AOCs. In all, 195 SWMUs and 209 AOCs have been identified at the CNC (M.A. Hunt, U.S. Navy, oral commun., 2000).

Geologic Setting

The geology of the North Charleston area and the CNC site is described fully in Weems and Lemon (1993) and EnSafe/Allen & Hoshall, Inc. (2000), and is briefly summarized here (fig. 2). The Ashley Formation is the deepest stratigraphic unit considered beneath the CNC in this report, and it consists of dense, light olive-brown, fine-grained, phosphatic calcarenite of Oligocene age. The Ashley Formation is laterally continuous throughout the North Charleston study area and ranges between 30 and 60 ft thick.

The Wando Formation is present as surficial sediment except near Noisette and Shipyard Creeks, where it is displaced by Holocene silty mud. The Wando Formation, ranging between 12 and 60 ft thick and consisting of fine-grained silts and clays deposited in transgressive coastal, fluvial, and estuarine environments during Quaternary time, unconformably overlies the Ashley Formation at the CNC (Weems and Lemon, 1993; B.G. Campbell, U.S. Geological Survey, oral commun., 2000). Heterogeneous sands, silts, and clay lenses of the Wando Formation obscure contact with lower units in some places.

SYSTEM	SERIES	STRATIGRAPHIC UNIT	MAJOR LITHOLOGY	THICKNESS (feet)	HYDROGEOLOGIC UNIT	
Quaternary	Holocene	Modern Marsh	Silty mud	0-5	Upper Surficial Aquifer	Surficial Aquifer System
	Pleistocene	Wando Formation	Sand and silt	2-35		
			Clay	8-40	Intervening Confining Unit	
			Sand, silt, and shell hash	2-48	Lower Surficial Aquifer	
Tertiary	Oligocene	Ashley Formation	Dense, fine-grained, phosphatic calcarenite	30-60	Confining Unit	

Figure 2. Generalized section of the hydrogeology of the surficial aquifer system for the Charleston Naval Complex, North Charleston, South Carolina.

Hydrogeologic Framework

The surficial aquifer system underlying the CNC consists of permeable sands and silts that form the upper and lower surficial aquifers, which are separated by a low permeability marsh clay layer (fig. 2). The hydrogeologic nomenclature used in this report is based on the conceptual model of the surficial aquifer system developed by Ensafe/Allen & Hoshall, Inc. (1998, 1999), as part of their RCRA facility investigations at the CNC.

The upper surficial aquifer overlies the marsh clay of the Wando Formation, and ranges in thickness from 2 to 21 ft in the northern zones (A and B) and southern zones (G, H, I) of the CNC (fig. 2). The maximum thickness (35 ft) of the upper surficial aquifer is recognized in some boreholes in the central area of the CNC, particularly zone E.

The laterally continuous, low permeability marsh clay layer, which acts as a confining unit to separate the upper and lower surficial aquifers, ranges in thickness from approximately 8 to 40 ft (fig. 2). Hydraulic connection is thought to be low between the two aquifers because of the thickness of the intervening clay confining unit (B.G. Campbell, U.S. Geological Survey, oral commun., 2000).

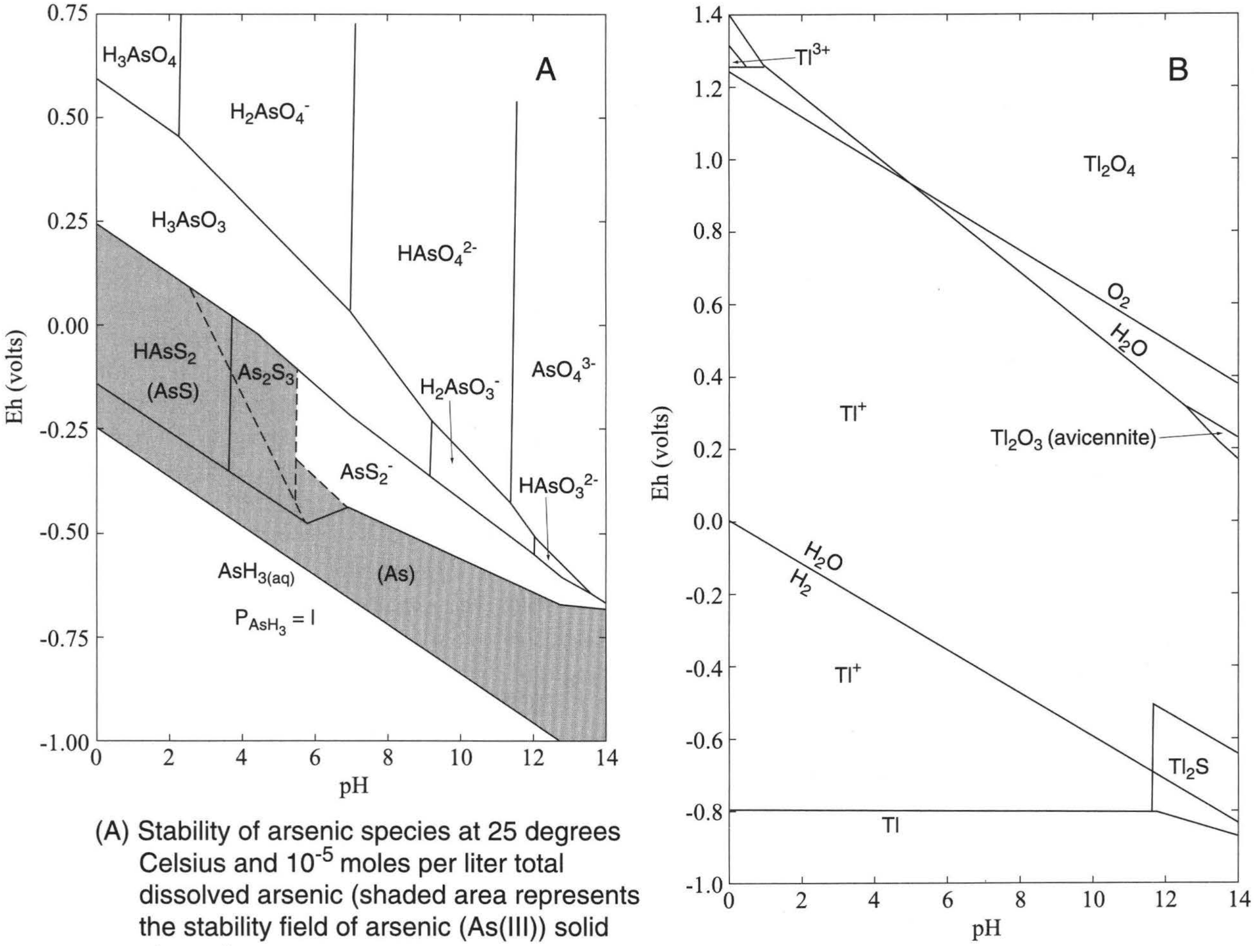
The lower surficial aquifer, which is confined beneath the marsh clay, is laterally continuous but variably thick across the study area. The lower surficial aquifer consists of fine- to coarse-grained sand, silt, and shell hash, and ranges in thickness from 2 to 48 ft (fig. 2). The maximum thickness (48 ft) of the lower surficial aquifer was determined from borehole measurements just south of Noisette Creek, in zone B (B.G. Campbell, U.S. Geological Survey, written commun., 2000). The calcarenite of the Ashley Formation forms a basal confining unit beneath the surficial aquifer system underlying the CNC.

GEOCHEMISTRY OF ARSENIC AND THALLIUM IN GROUND WATER AND SEDIMENT

The transport and fate of dissolved arsenic in ground water are complex because of variable reductionoxidation (redox) conditions that can occur in shallow unconfined aquifers. Inorganic, dissolved arsenic species exist in two valence states—arsenite (As(III)) and arsenate (As(V)). Speciation exerts some control on the mobility of arsenic in ground water. In natural water, arsenite occurs primarily as arsenous acid (H_3AsO_3, $pK_a = 9.2$) or the dissociated oxyanion, $H_2AsO_3^-$; whereas, arsenate occurs as arsenic acid (H_3AsO_4, $pK_a = 2.2$) or the dissociated oxyanion, $H_2AsO_4^-$ ($pK_a = 6.98$; fig. 3).

The following discussion focuses on the transport and fate of arsenic species as they pertain to subsurface geochemical conditions at the CNC study area. The CNC was constructed on former saltmarsh sediments and fill, and surficial saltmarsh forms the southern boundary of the CNC along Shipyard Creek. Therefore, redox reactions associated with iron- and sulfur-rich sediments predominately control arsenic transport and fate. Geochemical controls on redox arsenite and arsenate in ground-water environments are not well characterized. Arsenite and arsenate are stable over the pH range of about 6 to 8, which is commonly found in ground water at the CNC (EnSafe/Allen and Hoshall, Inc., 2000). Arsenate dominates in oxic environments, and arsenite occurs with arsenate in anoxic environments. Because it is difficult to quantify inorganic arsenic species at concentrations as low as nanograms per liter, dissolved arsenic concentrations generally are reported as the sum of arsenite and arsenate.

Transport of dissolved arsenic species is affected by sorption or coprecipitation of arsenate with iron oxide surfaces and the redox environment. Arsenate sorbs preferentially to arsenite on kaolinite and illite clays as well as iron oxide surfaces (National Research Council,



(A) Stability of arsenic species at 25 degrees Celsius and 10^{-5} moles per liter total dissolved arsenic (shaded area represents the stability field of arsenic (As(III)) solid phases).

(B) Stability of thallium species at 25 degrees Celsius and 10^{-8} moles per liter total dissolved thallium.

Figure 3. Stability of (A) arsenic and (B) thallium species in water (arsenic diagram modified from Ferguson and Gavis, 1972; thallium diagram modified from Vink, 1998).

1999), most likely because arsenite occurs as an undissociated (neutral charge) acid below pH 9.2. Arsenite mobility along a ground-water flow path, therefore, is greater than the mobility of arsenate under most ground-water conditions. If redox conditions favor arsenite, then it is possible for dissolved arsenic to be detected in ground water away from a source. Redox conditions that favor arsenite mobility include the absence of dissolved oxygen and the presence of electron donors, such as dissolved sulfides ($H_2S_{(aq)}$, HS^-) and ferrous iron (Fe^{2+}).

Sinks for inorganic arsenite and arsenate species are similar to their mineral sources. Arsenic is a common trace element in sulfide minerals such as pyrite; arsenic is incorporated into pyrite mineral lattices primarily as arsenite (Savage and others, 2000). If amorphous iron sulfide phases (common in anoxic mud) precipitate in pore waters, arsenite may be associated with the solid phase. The availability of dissolved or gaseous oxygen results in the formation of amorphous iron oxides or the mineral goethite ($FeO(OH)$) in soil. In this environment, arsenate may sorb or coprecipitate with oxidized iron solid phases. Unconfined aquifers are characterized by changing redox conditions as a result of recharge events. Thus, dissolved arsenic can travel along a ground-water flow path when redox conditions favor the dissolved species, primarily arsenite.

Thallium is a metallic trace element that occurs naturally in copper, gold, zinc, and cadmium-rich sulfide ore deposits. Coal-fired furnaces at smelting operations release thallium into the environment as particulate matter (Kaplan and Mattigod, 1998). Dissolved thallium occurs primarily as the monovalent cation, Tl^+, particularly where sulfate, bromide, and chloride concentrations are low. Dissolved thallium is stable over the range of Eh and pH measured in natural ground water and fresh surface water (Kaplan and Mattigod, 1998). Under oxidized (Eh greater than 0.4 volts) and alkaline (pH greater than 10) conditions, dissolved- and solid-phase thallium oxide species are stable (Lin and Nriagu, 1998). Literature values reported for total dissolved thallium concentrations in ground water range from 0.001 to 0.550 μg/L, using graphite furnace atomic absorption spectrophotometry (GFAAS) or inductively coupled plasma-mass spectroscopy (ICP-MS) methods (Lin and Nriagu, 1999).

METHODS OF DATA COLLECTION AND ANALYSIS

As part of the closure activities at a military facility, RCRA regulations require quarterly water sampling for at least 1 year to characterize the magnitude and geographic extent of contaminants in ground water. Three classes of wells were examined for this study—SWMU wells, AOC wells, and grid wells. SWMU and AOC wells are located at or near the sites of specific industrial activities. Grid wells are uniformly located in a grid pattern throughout the CNC. Using water-quality data from RCRA facility investigations conducted during 1994–99 by EnSafe/Allen & Hoshall, Inc. (1998, 1999), the objective for this study was to determine the overall magnitude and geographic extent of arsenic and thallium rather than focus on temporal changes in concentrations in any specific well or CNC zone.

Analytical Methods for Detecting Dissolved Arsenic and Thallium

Ground-water samples from CNC wells were analyzed using USEPA methods and following quality-assurance/quality-control requirements. The ground-water samples and acid extracts of sediments were analyzed for arsenic following USEPA method 200.8 using inductively coupled plasma-atomic emission spectroscopy (ICP-AES). The practical minimum detection limit for arsenic in a water sample using ICP-AES is 4 μg/L (U.S. Environmental Protection Agency, 1994); however, all laboratory-reported measured concentrations were used to calculate the mean concentrations in appendix 1, even if the measured concentrations were less than the practical minimum detection limit. The current (2002) drinking-water MCL for arsenic is 10 μg/L (U.S. Environmental Protection Agency, 2001). Currently, the analytical detection limit for arsenic is lower than the MCL, so measured concentrations of arsenic in ground water can be interpreted in a regulatory context with confidence.

Ground-water samples and acid extracts of sediments from the CNC study area also were analyzed for thallium following USEPA method 200.8 using ICP-AES. The minimum detection limit and the drinking-water MCL are 2 μg/L (U.S. Environmental Protection Agency, 1994). Dissolved thallium analyses using ICP-AES are problematic because thallium does not ionize readily in plasma, and the thallium spectral line is characterized by a doublet peak. These spectral characteristics mean that thallium detection at low concentrations (micrograms per liter) can be difficult during routine ICP-AES analysis. Lower detection limits can be obtained by using GFAAS or ICP-MS methods. Because thallium concentrations in CNC ground-water samples were obtained by using the ICP-AES method (M.A. Hunt, U.S. Navy, oral commun., 2000), it is possible that the laboratory-determined practical minimum detection limit may be higher than the drinking-water MCL. The laboratory-reported concentration for thallium was used to calculate the mean concentrations in appendix 1, even if the reported concentration was below the practical minimum detection limit.

Many of the ground-water samples containing thallium concentrations at or near the minimum detection limit were coded with either a U, indicating that the concentration was measured below the detection limit; a J, indicating that the concentration of thallium was detected semi-quantitatively; or an R, indicating that the analyzed concentration was rejected on the basis of instrumental performance. All U- and J-coded data were compiled in this study. Four thallium analyses and three arsenic analyses (all representing samples from different wells) were discarded from the data set (listed in app. 1), because the R code indicated failure of quality-assurance/quality-control criteria as determined by the analytical laboratory.

Compilation of Ground-Water Arsenic and Thallium Data

Ground-water data were obtained from RCRA facility investigations conducted during 1994–99 by EnSafe/Allen & Hoshall, Inc. (1998, 1999). The data set analyzed for this report consists of arsenic and thallium concentrations measured in water samples collected from 604 wells located throughout the CNC. Typically, each well was sampled four times (once each quarter for 1 year), although the number of sampling events at any given well ranged from one to seven. Table 1 summarizes the number of sampling events for all wells at the CNC.

Mean dissolved arsenic and thallium concentrations were calculated for each well by using all sampling data (app. 1). Following statistical compilation, mean arsenic and thallium concentrations were associated with northing and easting coordinates in the upper and lower surficial aquifers for spatial representation in a GIS.

Compilation of Background Concentrations of Arsenic and Thallium in Ground Water

Few data exist to assess the local and regional background concentrations of arsenic and thallium in the surficial aquifer system in the Charleston area. Ground-water quality conditions reported for South Carolina (for example, Bucklin, 1997) commonly exclude analyses of samples from the surficial aquifer because of the difficulty of separating background arsenic and thallium concentrations from those affected by elevated natural or industrial sources. Similarly, no ground-water data from Charleston County were tabulated in a national survey of arsenic concentrations in potential drinking-water sources (Focazio and others, 2000). The only available data regarding background concentrations of arsenic in the surficial aquifer were values measured in ground-water samples collected from designated background wells at nearby Superfund national priority list sites (table 2).

Thallium concentrations in ground-water samples from the surficial aquifer system were not available from previous investigations. As a result, background concentrations of thallium in ground water are interpreted in this report to be the minimum detection limit (2 μg/L).

Extraction and Measurement of Arsenic and Thallium in Sediment

In 1995, an 11.8-ft-long sediment core was obtained from Shipyard Creek marsh by using the electric-powered vibracore method. The core was cut in half longitudinally with a circular saw and sampled within 3 days of collection. Sediment samples were collected from the center of the core in about 0.75-in. intervals for a total of 160 samples, labeled, and stored in plastic bags. Prior to extraction, sediment samples were air dried, and then crushed with a mortar and pestle. Approximately 1.0-g (weighed to 0.0001-g) subsamples were placed in 50-mL beakers for extraction. Sediment-bound metals were acid extracted (80 °C, nitric and hydrochloric acid mixture) following USEPA method 200.7 and analyzed using ICP-AES following USEPA method 200.8 (U.S. Environmental Protection Agency, 1994). Similarly, the same acid extracts were analyzed to determine if sediment-bound arsenic and thallium concentrations increased over time.

DISTRIBUTION OF ARSENIC AND THALLIUM IN GROUND WATER AND SEDIMENT AT THE CHARLESTON NAVAL COMPLEX

Mean arsenic and thallium concentrations in ground-water and sediment samples from the surficial aquifer system were examined to assess the magnitude and spatial distribution of contamination at the CNC. This assessment proceeded in two steps. First, mean arsenic (n=603) and thallium (n=604) concentrations were calculated for water samples from each well at the CNC (app. 1). In wells with only one sample, the actual concentration was reported in appendix 1. Then, the mean

Table 1. Summary of arsenic and thallium sampling events for wells screened in the upper and lower surficial aquifers at the Charleston Naval Complex, South Carolina, during 1994–99

Aquifer identification (fig. 2)	Sampling period	Element	Number of wells having 1 to 7 sampling events							Total number of wells sampled
			1	2	3	4	5	6	7	
Zone A										
Upper surficial aquifer	Sept. 1995–Oct. 1998	Arsenic	7	2	5	16	8	0	0	38
		Thallium	7	2	8	11	11	0	0	39
Lower surficial aquifer	Sept. 1995–Oct. 1998	Arsenic	4	0	5	6	1	0	0	16
		Thallium	4	0	5	6	1	0	0	16
Zone B										
Upper surficial aquifer	Dec. 1995–Oct. 1996	Arsenic	0	0	0	4	0	0	0	4
		Thallium	0	0	0	4	0	0	0	4
Lower surficial aquifer	Dec. 1995–Oct. 1996	Arsenic	0	0	0	2	0	0	0	2
		Thallium	0	0	0	2	0	0	0	2
Zone C										
Upper surficial aquifer	May 1995–June 1999	Arsenic	1	0	0	18	6	4	0	29
		Thallium	1	0	0	18	8	2	0	29
Lower surficial aquifer	June 1995–June 1996	Arsenic	0	0	0	2	0	0	0	2
		Thallium	0	0	0	2	0	0	0	2
Zone D										
Upper surficial aquifer	Mar. 1996–Jan. 1997	Arsenic	0	0	0	1	0	0	0	1
		Thallium	0	0	0	1	0	0	0	1
Lower surficial aquifer	Mar. 1996–Jan. 1997	Arsenic	0	0	0	1	0	0	0	1
		Thallium	0	0	0	1	0	0	0	1
Zone E										
Upper surficial aquifer	Mar. 1996–Jan. 1999	Arsenic	0	10	1	118	2	0	0	131
		Thallium	0	10	0	119	2	0	0	131
Lower surficial aquifer	Mar. 1996–Jan. 1999	Arsenic	0	1	0	56	1	0	0	58
		Thallium	0	1	0	55	2	0	0	58
Zone F										
Upper surficial aquifer	Dec. 1996–May 1999	Arsenic	5	3	4	36	1	0	0	49
		Thallium	5	2	4	37	1	0	0	49
Lower surficial aquifer	Dec. 1996–May 1999	Arsenic	0	0	1	7	0	0	0	8
		Thallium	0	0	1	7	0	0	0	8
Zone G										
Upper surficial aquifer	Dec. 1996–Jan. 1999	Arsenic	0	48	4	26	4	0	0	82
		Thallium	0	48	4	27	3	0	0	82
Lower surficial aquifer	Dec. 1996–Dec. 1997	Arsenic	0	0	0	2	0	0	0	2
		Thallium	0	0	0	2	0	0	0	2
Zone H										
Upper surficial aquifer	Nov. 1994–Aug. 1998	Arsenic	13	1	10	56	2	1	4	87
		Thallium	13	0	10	57	7	0	0	87
Lower surficial aquifer	Nov. 1994–May 1999	Arsenic	5	0	0	22	0	0	2	29
		Thallium	5	0	0	21	3	0	0	29
Zone I										
Upper surficial aquifer	Jan. 1996–May 1999	Arsenic	3	1	28	6	2	5	0	45
		Thallium	3	1	28	5	3	5	0	45
Lower surficial aquifer	Dec. 1995–Jan. 1999	Arsenic	0	0	14	3	1	1	0	19
		Thallium	0	0	13	4	1	1	0	19

Table 2. Background arsenic concentrations in water samples from the surficial aquifer system reported at Comprehensive Environmental Restoration, Compensation, and Liability Act national priority list sites in Charleston, South Carolina

[µg/L, microgram per liter; NPL, national priority list; —, not reported]

Site identification (fig. 1)	Aquifer	Well number	Arsenic, in µg/L	Reference
Macalloy NPL site	Upper surficial aquifer	—	27.99	Ensafe/Allen, & Hoshall, Inc., 2000.
	Lower surficial aquifer	—	14.98	Ensafe/Allen, & Hoshall, Inc., 2000.
Charleston Harbor National Park Service site	Upper surficial aquifer	MW-2	5	Chester Environmental, Inc., 1993.
	Upper surficial aquifer	MW-6	6	Chester Environmental, Inc., 1993.
Calhoun Park site, South Carolina Electric & Gas property	Upper surficial aquifer	BG-01A	24.9	Chester Environmental, Inc., 1994.
	Upper surficial aquifer	BG-012A	2	Chester Environmental, Inc., 1994.
	Lower surficial aquifer	BG-01D	4	Chester Environmental, Inc., 1994.
Calhoun Park site, Ansonborough Homes	Upper surficial aquifer	AMW-3	14	Davis & Floyd, Inc., 1990.
Koppers NPL site	Upper surficial aquifer	MW-20S	2	ENSR Consulting & Engineering, Inc., 1993.
	Upper surficial aquifer	MW-20D[a]	3, 6	ENSR Consulting & Engineering, Inc., 1993.
	Lower surficial aquifer	MW-20D	3	ENSR Consulting & Engineering, Inc., 1995.

[a] Two separate samples were reported for this well by ENSR Consulting & Engineering, Inc. (1993).

concentrations for arsenic and thallium in each zone—called the zone mean concentrations in this report—were calculated for the upper and lower surficial aquifers by using the mean arsenic and thallium concentrations calculated for each well (table 3). The grouping of wells by zone and aquifer, and compilation of associated arsenic and thallium concentrations enabled the assessment of adjacent SWMUs or AOCs as potential point sources.

Well locations were plotted by using State plane coordinates and, based on the mean arsenic concentrations in the ground-water samples, each well was assigned to one of three groups—wells with mean arsenic concentrations of less than 10 µg/L, wells with mean arsenic concentrations from 10 to 50 µg/L, and wells with mean arsenic concentrations greater than 50 µg/L. The well groups were defined by using existing (10 µg/L) and past (50 µg/L) drinking-water MCLs (U.S. Environmental Protection Agency, 2001). The distributions of mean arsenic concentrations in the upper and lower surficial aquifers below the CNC are shown in plates 1 and 2, respectively.

Spatial distribution of thallium in ground water at the CNC is more difficult to interpret. Of the 604 wells at the CNC, water samples from 590 wells have mean thallium concentrations greater than 2 µg/L (app. 1), which exceeds the MCL for thallium. For reasons mentioned earlier, instrument problems precluded interpretation of thallium concentrations near the 2-µg/L MCL. Water samples from 21 wells have mean thallium concentrations of 10 µg/L or greater. In this report, the spatial trends for thallium concentrations in ground water are discussed relative to an arbitrary mean concentration of 10 µg/L, but are not depicted graphically on plates 1 and 2.

Statistical Interpretation of Arsenic in Ground Water

The CNC data within each zone were evaluated for normal (equal) distribution about the zone mean concentration. Z-score (standard-score) histograms for each zone—except zone D—were compared to a normal distribution curve (fig. 4). Zone D has only one mean concentration and could not be statistically evaluated. The histograms depict mean arsenic concentrations as Z-scores, which are standard deviations from the mean value. If the data follow a bell-shaped (normally distributed) curve, then approximately 95 percent of the data should have a Z-score between –2 and 2. Several of the zones, particularly for the lower surficial aquifer, did not have enough data for statistical analysis: zones B (n=4, upper surficial aquifer; n=2, lower surficial aquifer), C (n=2, lower surficial aquifer), D (n=1, upper surficial aquifer; n=1, lower surficial aquifer), and G (n=2, lower surficial aquifer). In zones that have a large number of wells, the data were not normally distributed,

Table 3. Zone mean arsenic and thallium concentrations in the upper and lower surficial aquifers beneath the Charleston Naval Complex, South Carolina

[µg/L, microgram per liter; —, no data]

Zone	Aquifer	Number of wells	Mean concentration, in µg/L	Minimum concentration, in µg/L	Maximum concentration, in µg/L	Standard deviation	Coefficient of variance
			Arsenic				
A	Upper surficial aquifer	38	15	1.3	111	22	1.5
	Lower surficial aquifer	16	4.2	1.0	15	4.6	1.1
B	Upper surficial aquifer	4	6.8	2.8	11	4.1	.6
	Lower surficial aquifer	2	5.2	2.8	7.5	3.3	.6
C	Upper surficial aquifer	29	10	2.7	90	18	1.7
	Lower surficial aquifer	2	2.7	2.7	2.7	0	0
D	Upper surficial aquifer	1	3.2	3.2	3.2	—	—
	Lower surficial aquifer	1	4.1	4.1	4.1	—	—
E	Upper surficial aquifer	131	13	2.3	285	28	2.2
	Lower surficial aquifer	58	15	2.2	97	23	1.5
F	Upper surficial aquifer	49	18	2.2	109	25	1.4
	Lower surficial aquifer	8	7.1	2.1	14	4.8	.7
G	Upper surficial aquifer	82	17	2.3	339	41	2.4
	Lower surficial aquifer	2	22	2.4	42	28	1.3
H	Upper surficial aquifer	87	13	2.1	327	35	2.8
	Lower surficial aquifer	29	7.2	1.9	55	10	1.4
I	Upper surficial aquifer	45	14	.9	166	27	1.9
	Lower surficial aquifer	19	5.0	3.3	11	2.0	.4
All zones	Upper surficial aquifer	466	14	.9	339	31	2.2
	Lower surficial aquifer	137	10	1	97	16	1.6
			Thallium				
A	Upper surficial aquifer	39	3.0	1.6	5.5	0.9	0.1
	Lower surficial aquifer	16	5.8	1.6	68	1.3	1.1
B	Upper surficial aquifer	4	3.2	3.4	25	1.3	.7
	Lower surficial aquifer	2	7.9	3.3	25	9	.6
C	Upper surficial aquifer	29	13	2.3	14	2	.5
	Lower surficial aquifer	2	14	3.2	3.2	0	0
D	Upper surficial aquifer	1	4.6	4.6	4.6	—	—
	Lower surficial aquifer	1	3.2	5	5	—	—
E	Upper surficial aquifer	131	3.9	2.7	5.4	.5	.1
	Lower surficial aquifer	58	5	2.7	8.7	1	1.5
F	Upper surficial aquifer	49	4.8	1.6	9	1.3	.3
	Lower surficial aquifer	8	4.2	4.4	5.6	.4	.7
G	Upper surficial aquifer	82	4.8	3.9	8.4	1	.2
	Lower surficial aquifer	2	4.8	4.7	5.1	.3	1.3
H	Upper surficial aquifer	87	5.3	2.2	33	5.1	1
	Lower surficial aquifer	29	4.9	2.4	45	8.2	1.4
I	Upper surficial aquifer	45	3.9	1.8	5.6	1	.3
	Lower surficial aquifer	19	8.5	3.5	7.5	1	.4
All zones	Upper surficial aquifer	467	4.4	1.6	33	2.7	.6
	Lower surficial aquifer	137	5.8	1.6	68	7.1	1.2

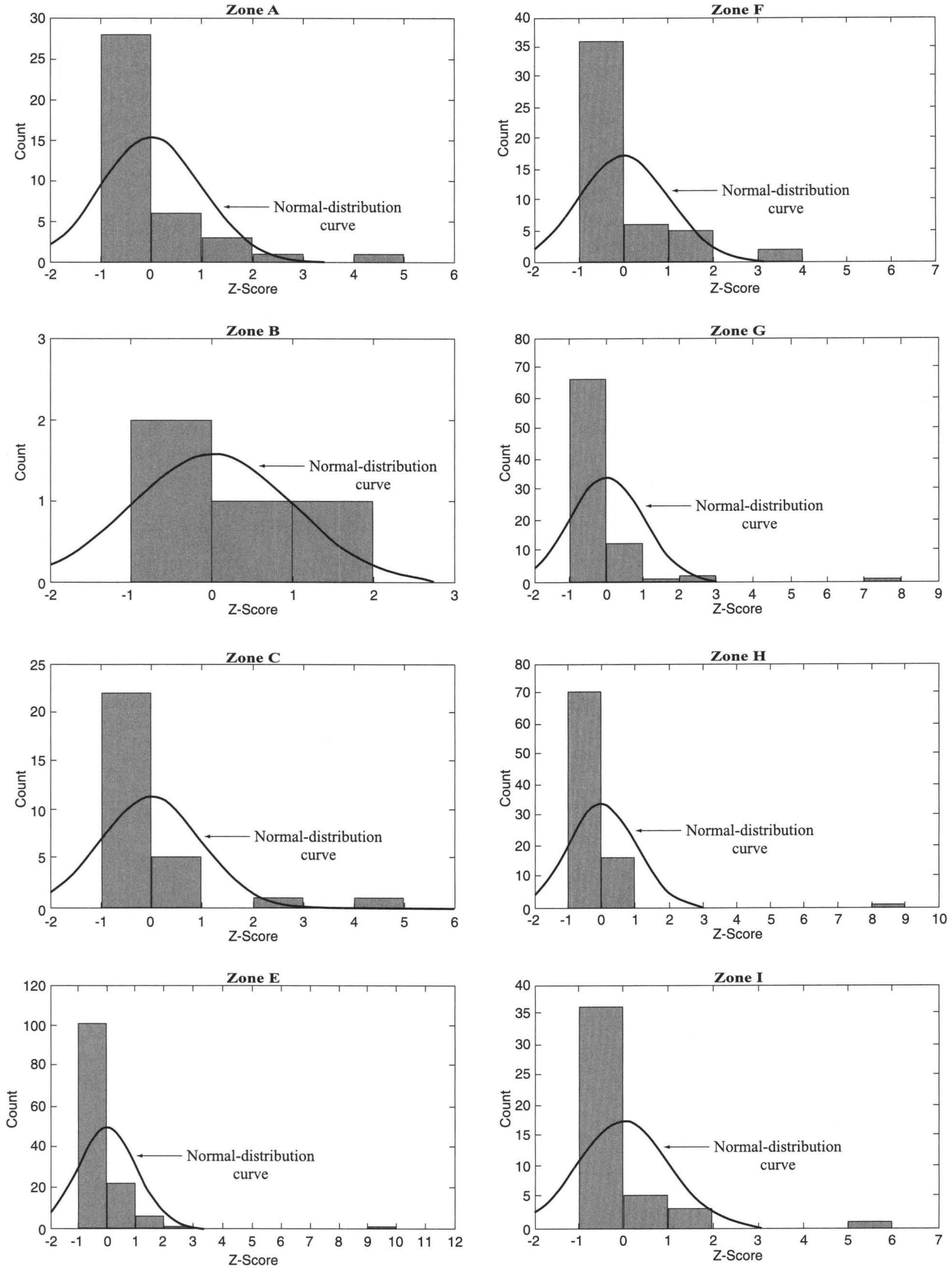


Figure 4. Z-score histograms of mean arsenic concentrations in water samples from wells screened in the upper surficial aquifer in selected zones at the Charleston Naval Complex, South Carolina.

especially in zones that had wells with mean arsenic concentrations greater than the previous drinking-water MCL (50 µg/L) (table 4). These few data points tend to skew the distribution toward greater positive Z-scores and raise the zone mean concentration and the standard deviation about the mean in each zone. Data with Z-scores larger than 2 are more than 2 standard deviations greater than the zone mean concentration and were considered outliers. So, the Z-scores were used to identify arsenic outliers within the data set for each zone—except zone D—in the upper surficial aquifer, even if they are not part of a well cluster.

Mean arsenic concentrations were calculated for each well screened in the upper (n=466) and lower (n=137) surficial aquifers (app. 1). Mean arsenic concentrations ranged from 0.9 to 339 µg/L in the upper surficial aquifer and from 1.0 to 97.4 µg/L in the lower surficial aquifer (app. 1). Zone mean arsenic concentrations (that is, means for each CNC zone) ranged from 3.2 to 18 µg/L in the upper surficial aquifer and from 2.7 to 22 µg/L in the lower surficial aquifers (table 3). All zone mean arsenic concentrations in the upper and lower surficial aquifers were below the previous drinking-water MCL of 50 µg/L. Background arsenic concentrations in water samples from the wells screened in the upper surficial aquifer and located near the CNC ranged from 2 to almost 28 µg/L (table 2).

To interpret arsenic concentrations in ground water in the context of regulatory guidelines, concentration ranges in table 4 were chosen to represent previous and current drinking-water MCLs. The 10-µg/L MCL replaced the previous MCL of 50 µg/L (National Research Council, 1999; U.S. Environmental Protection Agency, 2001). Mean arsenic concentrations in water exceeded 10 µg/L in 29 percent (135 of 466) of the wells screened in the upper surficial aquifer and in 23 percent (31 of 137) of the wells screened in the lower surficial aquifer.

Table 4. Number of wells in each zone of the Charleston Naval Complex where water samples from the upper and lower surficial aquifers had mean arsenic concentrations less than 10 micrograms per liter (µg/L), ranging from 10 to 50 µg/L, and greater than 50 µg/L

[<, less than; µg/L, microgram per liter; >, greater than]

Zone	Aquifer	Total number of wells	Number of wells with arsenic concentrations			Percentage of wells with arsenic concentrations exceeding 10 µg/L
			<10 µg/L	10–50 µg/L	>50 µg/L	
A	Upper surficial aquifer	38	26	10	2	32
	Lower surficial aquifer	16	14	2	0	12
B	Upper surficial aquifer	4	3	1	0	25
	Lower surficial aquifer	2	2	0	0	0
C	Upper surficial aquifer	29	22	6	1	24
	Lower surficial aquifer	2	2	0	0	0
D	Upper surficial aquifer	1	1	0	0	0
	Lower surficial aquifer	1	1	0	0	0
E	Upper surficial aquifer	131	93	32	6	24
	Lower surficial aquifer	58	39	14	5	33
F	Upper surficial aquifer	49	31	14	4	37
	Lower surficial aquifer	8	6	2	0	25
G	Upper surficial aquifer	82	57	21	4	31
	Lower surficial aquifer	2	1	1	0	50
H	Upper surficial aquifer	87	62	24	1	29
	Lower surficial aquifer	29	23	5	1	21
I	Upper surficial aquifer	45	36	6	3	20
	Lower surficial aquifer	19	18	1	0	5
All zones	Upper surficial aquifer	466	331	114	21	29
	Lower surficial aquifer	137	106	25	6	23
	Total	603	437	139	27	28

Statistical Interpretation of Thallium in Ground Water

Mean thallium concentrations were calculated for each well screened in the upper and lower surficial aquifers (app. 1). Mean thallium concentrations ranged from 1.6 to 32.6 µg/L in the upper surficial aquifer and from 1.6 to 67.7 µg/L in the lower surficial aquifer (app. 1). Zone mean thallium concentrations ranged from 3.2 to 13 µg/L in the upper surficial aquifer and from 3.2 to 14 µg/L in the lower surficial aquifers (table 3).

Although the data supporting quality-assurance and quality-control procedures for thallium analyses were not available, thallium concentrations less than 5.0 µg/L were considered semiquantitative for the following two reasons. First, all thallium analyses were performed by using ICP-AES, which is the least sensitive method of analysis for thallium. Second, nearly all ground-water samples with thallium concentrations less than 5.0 µg/L were coded with a "J" in the original database, indicating the analyses were semiquantitative. Therefore, to distinguish between samples having elevated thallium concentrations and samples at background levels, the criterion to define an elevated mean thallium concentration was set arbitrarily at equal to or greater than 10 µg/L. Mean thallium concentrations in water equaled or exceeded 10 µg/L in 3 percent (12 of 467) of the wells screened in the upper surficial aquifer, and in 7 percent (9 of 137) of the wells screened in the lower surficial aquifer (app. 1).

Spatial Distribution of Arsenic in Ground Water

Analyses indicate that mean arsenic concentrations of 10 µg/L or greater occur in water samples collected from clusters of wells penetrating the upper (12 clusters) and lower (1 cluster) surficial aquifers at the CNC. A well cluster is quantitatively defined as three or more wells within a single SWMU or AOC within one zone, where the mean arsenic concentrations exceeded 10 µg/L. In the following discussion, mean arsenic concentrations of 10 µg/L or greater in water from a well cluster within a single SWMU and AOC are evaluated with respect to activities in adjacent SWMUs or AOCs. If a well has a Z-score greater than 2 and is not part of a cluster, it is considered statistically to be an outlier from the rest of the data in a given zone and also is identified in the following discussion.

The greatest number of wells with mean arsenic concentrations exceeding 10 µg/L in the upper (38 of 131 wells) and lower (19 of 58 wells) surficial aquifers was in zone E (table 4). SWMU 065 (lead-storage area) in zone E contains a cluster of four wells (E065-3, 4, 5 and 8) in the upper surficial aquifer (app. 1). AOC 556 (dry docks 3 and 4) contains a cluster of three grid wells (EGD-1, 2, and 3) and includes SWMU 106 (blast area, dry dock 3) with one well (E106-1) as part of this cluster in the upper surficial aquifer. AOC 605 (waste-paint storage area) is adjacent to the boundary of AOC 556 and also contains one well (E605-3) with a high mean arsenic concentration. Examples of other SWMUs and AOCs in the upper surficial aquifer where mean arsenic concentrations in water samples from wells exceeded 10 µg/L include a foundry (E083-1), a forge shop (E538-1), a boiler house (E550-1), and a former locomotive shop (E563-1, 2). Many of these SWMUs and AOCs likely involved coal storage and burning, which may have contributed arsenic to adjacent ground water and soil. For wells in the lower aquifer, four wells (E145-1D, E566-1D, E574-1D, and E580-1D) in the vicinity of dry dock 5 have Z-scores greater than 2, but are not assigned to the same SWMU or AOC and are not considered a cluster. In addition to the grid wells in the cluster at AOC 556, water from many of the other grid wells in zone E also had arsenic concentrations equal to or greater than 10 µg/L (EGD-6, 7D, 8, 9, 9D, 12D, 14, 15D, 16, 16D, 24D, 27, 29, and 29D), although sources of elevated arsenic concentrations could not be defined conclusively for grid wells. Grid wells EGD-2 and EGD-8 have Z-scores greater than 2 and are interpreted to be outliers from the rest of the data distribution for the upper surficial aquifer in zone E.

Zone E is the oldest and most intensively developed area of the CNC. Zones C, D, and E were built on a former tidal creek that was filled during the early 1900's (B.G. Campbell, U.S. Geological Survey, oral commun., 2000). Flow and reaction of ground water through the fill material may have contributed to the presence of arsenic in water from many of the zone E wells. Although the greatest number of elevated arsenic concentrations were found in water samples from wells in zone E, no particular activity at a SWMU or an AOC could be definitively linked as a potential source of the elevated concentrations.

In zone A, mean arsenic concentrations in water samples from 32 percent (12 of 38 wells) of the wells screened in the upper surficial aquifer exceeded 10 µg/L (table 4). Water samples from 9 of 19 wells in the upper surficial aquifer at SWMU 039 (a drum-storage area) had mean arsenic concentrations greater than 10 µg/L. These nine wells represent a cluster as defined in this report. Mean arsenic concentrations were less than 10 µg/L in all but two samples collected from lower surficial aquifer wells in zone A (A039-8D, AGD-3D; app. 1).

In zone C, mean arsenic concentrations in water samples from 24 percent (7 of 29 wells) of the wells screened in the upper surficial aquifer equaled or exceeded 10 µg/L (table 4), including two well clusters—three wells in SWMU 044 (coal-storage area) and three wells in SWMU 047 (burning dump). Water samples from both wells screened in the lower surficial aquifer have mean arsenic concentrations less than 10 µg/L (app. 1).

In zone F, mean arsenic concentrations in water samples from 37 percent (18 of 49 wells) of the wells screened in the upper surficial aquifer equaled or exceeded 10 µg/L (table 4). These wells are located at or near one of the following AOCs—607, dry-cleaning building (two wells in the upper surficial aquifer); 609, building 1346 gas station (six wells, including five identified by "SME;" app. 1); and 613, locomotive shop (five wells, including three identified by "GEL"; app. 1). The wells at AOC 609 and AOC 613 represent clusters as defined in this report. Water samples from two fuel-delivery system wells (FDS-16B, 17B) had mean arsenic concentrations exceeding 50 µg/L. Of these two wells, FDS-16B has a Z-score in excess of 2. Mean arsenic concentrations in water samples exceeded 10 µg/L in two wells (F607-2D, 3D) screened in the lower surficial aquifer at AOC 607, dry-cleaning building.

In zone G, mean arsenic concentrations in water samples from 31 percent (25 of 82 wells) of the wells screened in the upper surficial aquifer exceeded 10 µg/L (table 4). These wells are near the following five SWMUs: 006, public works storage yard (three wells); 008, oil sludge pit (four wells, including two fuel-delivery system wells); 011, caustic pond (one well); 024, waste-oil reclamation (two wells); and 120, pier M lay-down area (two wells). SWMUs 006 and 008 represent well clusters. Water samples from one of the grid wells (GGD-1) screened in the upper aquifer in zone G, not associated with a specific SWMU or AOC, has a Z-score greater than 2. In the lower surficial aquifer, one of the two wells (GGD-2D) has a high mean arsenic concentration (41.9 µg/L; app. 1) and is within AOC 709.

A total of 54 upper surficial aquifer wells in zones E, F, and G are designated as "FDS" (fuel-delivery system), because they were installed to monitor ground-water quality adjacent to fuel tanks and pipes (app. 1). Water samples from 16 of the 54 wells have mean arsenic concentrations equal to or greater than 10 µg/L (app. 1). In zone G, water samples from eight FDS wells (FDS-12A, 12B, 13A, 13B, 13E, 14A, 14B, and 14C) in the upper surficial aquifer in AOC 709 have mean arsenic concentrations of 10 µg/L or greater and represent a cluster of wells. Locally reducing conditions resulting from petroleum degradation in the subsurface could favor arsenite mobility in the upper surficial aquifer at this site.

In zone H, mean arsenic concentrations in water samples from 29 percent (25 of 87 wells) of the wells screened in the upper surficial aquifer exceeded 10 µg/L (table 4). Water samples collected from 8 of 31 wells in the upper surficial aquifer at SWMU 009 (closed landfill) had mean arsenic concentrations exceeding 10 µg/L. Water samples from six wells in the lower surficial aquifer in zone H had mean arsenic concentrations exceeding 10 µg/L, including a cluster of five wells associated with SWMU 009 (closed landfill) and one grid well (HGD-1D) to the east of SWMU 009. The eight wells in the upper surficial aquifer and five wells in the lower surficial aquifer in SWMU 009 represent two clusters in zone H. This is the only well cluster defined in the lower aquifer at CNC. Locally reducing conditions resulting from leachate production in the closed landfill could favor arsenite mobility at SWMU 009. One other cluster of wells (H009-20, 21, 22, 23, and GEL-15) also is recognized in zone H at SWMU 196 (south landfill). Elsewhere in zone H, water samples from a few wells in the upper surficial aquifer had mean arsenic concentrations exceeding 10 µg/L, including four grid wells (app. 1). These elevated mean arsenic concentrations could be associated with activities at AOC H653, hobby shop (two wells); and AOC H655, oil-spill area (two wells).

In zone I, mean arsenic concentrations in water samples from 20 percent (9 of 45 wells) in the upper surficial aquifer and in 1 of 19 wells in the lower surficial aquifer exceeded 10 µg/L (table 4). Six of these wells are grid wells (IGD-4, 9, 13, 17, 19, and 19D). The four remaining wells are screened in the upper aquifer with each well at a separate SWMU or AOC—well I012-2 at SWMU 012, old fire-fighter training area; well I671-3 at SWMU 671, metering house; well I680-1 at SWMU 680, brake repair and welding area; and well I687-2 at SWMU 687, ammunition storage).

Spatial Distribution of Thallium in Ground Water

Of the 604 wells from which water samples were collected, only samples from 21 wells (3.5 percent) had mean thallium concentrations equal to or exceeding 10 µg/L (app. 1). Of these 21 wells, 14 wells are in zone H—a cluster of 4 wells inside SWMU 009 in the upper surficial aquifer; 2 wells just to the east of SWMU 009 screened in the upper surficial aquifer; 1 well inside and 3 wells adjacent to SWMU 009 screened in the lower surficial aquifer; and 4 grid wells, 2 screened in the upper surficial aquifer and 2 screened in the lower surficial aquifer to the east of SWMU 009. The local source of thallium likely is related to materials in the closed landfill. The remaining seven wells include three grid wells in zone B and one well (C044-1) in zone C screened in the upper surficial aquifer, and grid wells in zone A (two wells) and zone B (one well) screened in the lower surficial aquifer. No source of thallium was apparent near these wells.

Water samples had coincident elevated (equal to or greater than 10 µg/L) mean arsenic and thallium concentrations in 12 wells at the CNC. Of these, 10 wells are in zone H—6 wells in SWMU 009 and 1 grid well screened in the upper surficial aquifer, and 2 wells in SWMU 009 and 1 grid well in the lower surficial aquifer (app. 1). The remaining two wells include grid well AGD-3D screened in the lower surficial aquifer in zone A and grid well BGD-1 screened in the upper surficial aquifer in zone B. No correlation could be made, however, between elevated mean arsenic and mean thallium concentrations in the other 592 wells at the CNC (app. 1).

Sediment Quality

Arsenic concentrations in acid extracts of sediment core SYC-1 did not increase with depth (fig. 5; app. 2). The mean arsenic concentration from SYC-1 sediment samples (n=160) was 3.05 +/– 0.92 mg/kg, which falls within the standard error of the background mean arsenic concentration (1.5 +/– 2.7 mg/kg) reported by Canova (1999) for South Carolina sediments. Windom and others (1989) concluded that arsenic in estuarine and coastal

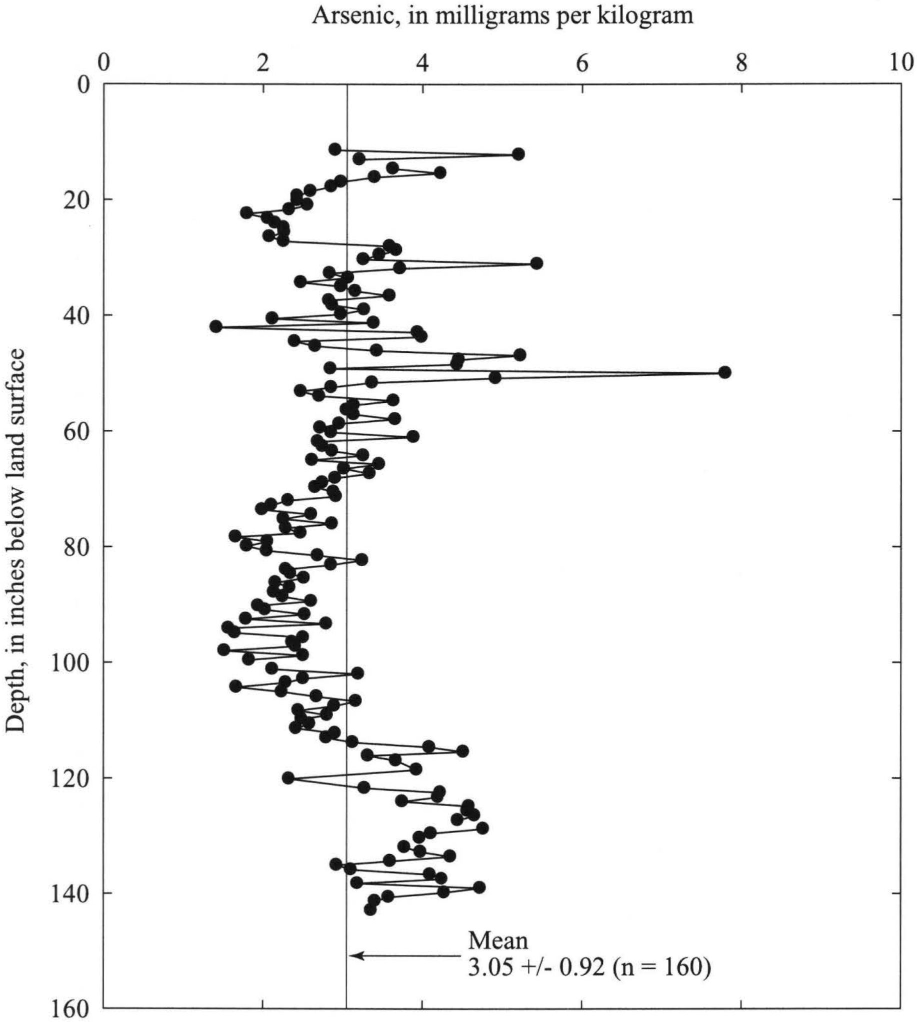


Figure 5. Arsenic concentrations with depth in Shipyard Creek marsh sediment core SYC-1 (arsenic concentration data are tabulated in appendix 2).

marine sediments covaried with aluminum concentrations, suggesting that a regional source for arsenic may be weathering of the continental crust. Coastal sediments containing arsenic (particularly in Georgia and South Carolina) may be related to the weathering and transport of phosphorites, which contain arsenic as a trace element. Arsenic concentrations reported for South Carolina phosphorite deposits range from 9 to 89 mg/kg (National Academy of Sciences, 1977), so the weathering of these rocks may be a potential source of arsenic in nearshore sediments. The influences of anthropogenic and natural effects on arsenic concentrations measured in SYC-1 sediments could not be separated. All but one sample (core depth = 50 in.) were less than the threshold-effects level of 7.24 mg/kg (U.S. Environmental Protection Agency, 1998).

Acid extracts of SYC-1 sediments were analyzed for thallium, but no thallium was detected. Of the 76 sediment analyses reported by Canova (1999), thallium was detected in only one sample (0.65 mg/kg), suggesting that the background thallium concentration in South Carolina sediments is below the minimum detection limit using the ICP-AES method.

SUMMARY

A qualitative statistical compilation of arsenic and thallium concentrations in ground-water samples collected from 1994 to 1999 was used to evaluate the magnitude and spatial distribution of these dissolved trace elements. Mean arsenic (n=603) and thallium (n=604) concentrations were calculated for each well at the Charleston Naval Complex; the concentration data then were subdivided by aquifer (upper and lower surficial aquifers) for each zone (A through I) to better understand arsenic and thallium distributions.

The magnitude of arsenic concentrations in ground water was evaluated in the context of the current (10 µg/L) and previous (50 µg/L) Federal drinking-water maximum contaminant levels. Mean arsenic concentrations in water samples from wells screened in the upper surficial aquifer exceeded 10 µg/L in all zones except zone D. In the upper surficial aquifer, mean arsenic concentrations ranged from 0.9 to 339 µg/L, with concentrations exceeding 10 µg/L in 29 percent (135 of 466) of the wells screened in this aquifer. In the lower surficial aquifer, mean arsenic concentrations ranged from 1.0 to 97.4 µg/L, with concentrations exceeding 10 µg/L in 23 percent (31 of 137) of the wells screened in this aquifer. Zone mean arsenic concentrations (that is, mean concentrations for each CNC zone) ranged from 3.2 to 18 µg/L in the upper surficial aquifer and from 2.7 to 22 µg/L in the lower surficial aquifer. In comparison, background arsenic concentrations in water samples from wells screened in the upper surficial aquifer and located near the CNC ranged from 2 to almost 28 µg/L. Arsenic concentrations in the surficial aquifer system at Charleston may be elevated locally as a result of historical (early 20th century) industrial activity or from interaction with phosphorites in aquifer material.

The spatial distribution of arsenic was evaluated qualitatively by using a geographic information system to depict the mean concentration in water from each well at the CNC. Wells were grouped based on mean arsenic concentrations—less than 10 µg/L, from 10 to 50 µg/L, and greater than 50 µg/L. Well clusters, defined as three or more wells in a SWMU or AOC with mean arsenic concentrations exceeding 10 µg/L, were identified in the upper surficial aquifer in association with 12 sites—SWMU 039 (a drum-storage area) in zone A, SWMUs 044 (coal-storage area) and 047 (burning dump) in zone C, SWMU 065 (lead-storage area) and AOC 556 (dry docks 3 and 4) in zone E, AOCs 609 (building 1346 gas station) and 613 (locomotive shop) in zone F, SWMUs 006 (public works storage yard) and 008 (oil sludge pit) and AOC 709 (fuel-delivery system) in zone G, and SWMUs 009 (closed landfill) and 196 (south landfill) in zone H. One well cluster was identified in the lower surficial aquifer in association with SWMU 009 (closed landfill) in zone H.

The magnitude of thallium concentrations in ground water was more difficult to evaluate because of analytical difficulties associated with the ICP-AES method. Mean thallium concentrations ranged from 1.6 to 32.6 µg/L in water samples from the upper surficial aquifer and from 1.6 to 67.7 µg/L in water samples from the lower surficial aquifer. Ground-water samples with mean thallium concentrations exceeding 10 µg/L were defined as having elevated concentrations, even though the thallium MCL is 2 µg/L. Water samples from nearly all wells (590 of 604) at the CNC had mean thallium concentrations greater than 2 µg/L. Water samples from 21 wells had mean thallium concentrations equal to or greater than 10 µg/L. Water samples had coincident elevated (equal to or greater than 10 µg/L) arsenic and thallium concentrations in 10 wells in zone H, 1 well in zone A, and 1 well in zone B.

The spatial distribution of thallium was evaluated in a manner similar to arsenic. Wells were grouped into two categories—those where mean thallium concentrations exceeded 10 µg/L and those where mean thallium concentrations were less than 10 µg/L. A well cluster (4 of 21 wells) was identified at SWMU 009, the closed landfill, where mean thallium concentrations in water exceeded 10 μg/L. The remaining wells were not identified as part of a well cluster. Ten of the wells are grid wells.

In 1995, a sediment core (SYC-1) was obtained from Shipyard Creek marsh, adjacent to zone I. This 11.8-ft-long core was sampled at 0.75-in.-long intervals (n=160) and processed for metals analyses. The mean arsenic concentration in SYC-1 was 3.05 +/– 0.92 mg/kg. The mean arsenic concentration and standard error calculated for SYC-1 sediment samples falls within the standard error for the background mean arsenic concentration reported for South Carolina sediments (1.5 +/– 2.7 mg/kg). All but one sample (core depth = 50 in.) was less than the threshold-effects level of 7.24 mg/kg. Acid extracts of SYC-1 sediments were analyzed for thallium, but no thallium was detected. These data indicate that no obvious reduction in arsenic or thallium concentration occurred with depth in sediment core SYC-1.

SELECTED REFERENCES

Agency for Toxic Substances and Disease Registry, 1992, Toxicological profile for thallium: U.S. Department of Health and Human Services, Public Health Service, Atlanta, Ga., accessed on June 13, 2002, at http://www.atsdr.cdc.gov/toxprofile/tp54.html.

———2000, Toxicological profile for arsenic: U.S. Department of Health and Human Services, Public Health Service, Atlanta, Ga., accessed on June 13, 2002, at http://www.atsdr.cdc.gov/toxprofile/tp2.html.

Azcue, J.M., and Nriagu, J.O., 1994, Arsenic—Historical perspectives, *in* Nriagu, J.O., ed., Arsenic in the environment, part I—Cycling and characterization: New York, John Wiley, p. 1–15.

Bucklin, C.F., 1997, South Carolina ambient ground water quality monitoring network: South Carolina Department of Health and Environmental Control, Bureau of Water, 34 p. + apps.

Canova, J.L., 1999, Elements in South Carolina inferred background soil and stream sediment samples: South Carolina Geology, v. 41, p. 11–26.

Chester Environmental, Inc., 1993, Tabulation of existing analytical data for the NPS property—Remedial investigation/feasibility study, Calhoun Park area site, Charleston, S.C.: Monroeville, Pa., Chester Environmental, Inc., app. E, table 12.

———1994, Preliminary site characterization study, Calhoun Park area site—Remedial investigation/feasibility study, v. I, SCE&G site, Charleston S.C.: Coraopolis, Pa., Chester Environmental, Inc., table 5-29.

Davis & Floyd, Inc., 1990, Initial ground-water investigation of the Calhoun Park/Ansonborough Homes site, December 1990—Calhoun Park area site remedial investigation/feasibility study, SCE&G site, Charleston, S.C.: Greenwood, S.C., Davis & Floyd, Inc., table 3-15.

Ecology & Environment, Inc., 1995, Archaeological sensitivity assessment for the disposal and reuse of Charleston Navy Base, North Charleston, S.C.: Ecology & Environment, Inc., 102 p.

Eisler, R., 1988, Arsenic hazards to fish, wildlife, and invertebrates—A synoptic review: U.S. Fish and Wildlife Service Biological Report 85 (1.12), 92 p.

EnSafe/Allen & Hoshall, Inc., 1998, Final Zone A RCRA Facility Investigation Report, Charleston Naval Complex, North Charleston, S.C., August 7, 1999: Mt. Pleasant, S.C., EnSafe/Allen & Hoshall, Inc., [variously paged].

———1999, Draft Zone I RCRA Facility Investigation Report, Charleston Naval Complex, North Charleston, S.C., March 1, 1999: Mt. Pleasant, S.C., EnSafe/Allen & Hoshall, Inc., [variously paged].

———2000, Remedial investigation/feasibility study work plan, Macalloy Corporation, North Charleston, S.C.: Memphis, Tenn., EnSafe/Allen & Hoshall, Inc., v. I, May 10, 2000, p. 4-3.

ENSR Consulting & Engineering, Inc., 1993, Final site characterization study summary—former Koppers site, Charleston S.C.: ENSR Consulting & Engineering, Inc., Phase I, v. I, app. E.2-Ground-water inorganics, p. 2-29, 2-30.

———1995, Remedial investigation report, former Koppers site, Charleston, S.C.: ENSR Consulting & Engineering, Inc., Technical Report, v. I, p. 4-17, table 4-17c, and app. J-2.

Ferguson, J.F., and Gavis, J., 1972, A review of the arsenic cycle in natural waters: Water Research, v. 6, p. 1259–1274.

Fetter, C.W., 1999, Contaminant hydrogeology (2d ed.): Saddle River, N.J., Prentice-Hall, p. 293.

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 Investigations Report 99-4279, 26 p.

Holmes, F.S., 1870, Phosphate rocks of South Carolina and the great Carolina marl bed: Charleston, S.C., Holmes Book House, 87 p.

Kaplan, D.I., and Mattigod, S.V., 1998, Aqueous geochemistry of thallium, *in* Nriagu, J.O., ed., Thallium in the environment: New York, John Wiley, p. 15–29.

Kartman, A.S., 1999, Aerial photographic analysis—Macalloy site, North Charleston, South Carolina: Las Vegas, Nev., Environmental Sciences Division, U.S. Environmental Protection Agency, 57 p.

Lide, D.R., ed., 1995, CRC handbook of chemistry and physics (76th ed.): Boca Raton, Fla., CRC Press, p. 4-29, p. 16-34.

Lin, T.S., and Nriagu, J.O., 1998, Speciation of thallium in natural waters, *in* Nriagu, J.O., ed., Thallium in the environment: New York, John Wiley, p. 31–58.

———1999, Thallium speciation in the Great Lakes: Environmental Science & Technology, v. 33, no.19, p. 3394–3397.

McNeil, J., 1985, Charleston's Navy Yard: Charleston, S.C., Coker Craft Press, 217 p.

Mirecki, J.E., and Delong, E.D., 1997, Chronology of sediment-bound transition metal deposition in the sediments of Shipyard Creek marsh, Charleston, S.C.: Geological Society of America, Southeastern Section Meeting, Abstracts with Programs v. 29, no. 3, p. 59.

National Academy of Sciences, 1977, Arsenic: Washington D.C., National Academy Press, p. 19.

National Research Council, 1999, Arsenic in drinking water: Washington D.C., National Academy Press, 310 p.

Nriagu, J.O., 1998, History, production, and uses of thallium, *in* Nriagu, J.O., ed., Thallium in the environment: New York, John Wiley, p. 1–14.

Savage, K.S., Tingle, T.N., O'Day, P.A., Waychunas, G.A., and Bird, D.K., 2000, Arsenic speciation in pyrite and secondary weathering phases, Mother Lode Gold District, Tuolumne County, California: Applied Geochemistry, v. 15, no. 8, p. 1219–1244.

U.S. Environmental Protection Agency, 1980, Ambient water-quality criteria for thallium: U.S. Environmental Protection Agency, Office of Water Regulations and Standards, EPA-440/5-80-074.

———1994, Methods for the determination of metals in environmental samples, supplement 1: Cincinnati, Ohio, Environmental Monitoring Systems, U.S. Environmental Protection Agency Report 600-R-94-111, 256 p.

———1996, Safe drinking water act amendment of 1996—General guide to provisions: U.S. Environmental Protection Agency, Office of Water, EPA-810-96-011, 20 p.

——— 1998, The incidence and severity of sediment contamination in surface waters of the United States, volume 1—National sediment survey: U.S. Environmental Protection Agency Report 823-R-97-006, [variously paged].

———2000a, National primary drinking water regulations: Federal register 40 CFR, parts 141 and 142, p. 334–612.

———2000b, National primary drinking water regulations; arsenic and clarifications to compliance and new source contaminants monitoring, proposed rule: Federal register 40 CFR, parts 141 and 142, v. 65, no. 121, p. 38887–38983.

———2001, National primary drinking water regulations; arsenic and clarifications to compliance and new source contaminants monitoring, final rule: Federal register 40 CFR, parts 9, 141, and 142, v. 66, no. 14, p. 6975–7066.

Vink, B.W., 1998, Thallium in the (sub)surface environment—Its mobility in terms of Eh and pH, *in* Nriagu, J.O., ed., Thallium in the environment: New York, John Wiley, p. 45–58.

Weems, R.E., and Lemon, E.M., Jr., 1993, Geology of the Cainhoy, Charleston, Fort Moultrie, and North Charleston quadrangles, Charleston and Berkeley Counties, South Carolina: U.S. Geological Survey Miscellaneous Investigations Map I-1935, 2 pls.

Windom, H.L., Schropp, S.J., Calder, F.D., Ryan, J.D., Smith, R.G., Jr., Burney, L.C., Lewis, F.G., and Rawlinson, C.H., 1989, Natural trace metal concentrations in estuarine and coastal sediments of the southeastern United States: Environmental Science & Technology, v. 23, no. 3, p. 314–320.

Appendix 1. Mean arsenic and thallium concentrations in water samples from wells at the Charleston Naval Complex, South Carolina

[µg/L, microgram per liter; GEOCODE, the depositional environment in which an upper surficial aquifer well is screened—U is upland soils, M is infilled marsh, and NA is not applicable to lower surficial aquifer wells; SWMU, solid-waste management unit; AOC, area of concern; FDS, fuel delivery system monitoring wells; GRID, regularly spaced wells throughout the Charleston Naval Complex; —, no data]

Well identifier	Well number	Mean arsenic concentration, in µg/L	Number of arsenic sampling events	Mean thallium concentration, in µg/L	Number of thallium sampling events	Well type	GEOCODE
Zone A, upper surficial aquifer							
A002-1	002GW00102	2.0	3	3.3	4	SWMU	U
A002-2	002GW00202	1.8	4	2.9	5	SWMU	U
A002-3	002GW00302	2.4	4	2.9	5	SWMU	U
A002-4	002GW00402	7.2	4	2.9	5	SWMU	U
A002-5	002GW00502	2.0	2	3.3	3	SWMU	U
A002-6	002GW00602	2.0	3	3.3	4	SWMU	U
A002-7	002GW007C1	4.8	1	1.6	1	SWMU	U
A002-8	002GW008C1	1.3	1	1.6	1	SWMU	U
A038-1	038GW00101	11	4	3.3	4	SWMU	U
A038-2	038GW00201	3.1	4	3.3	4	SWMU	U
A038-3	038GW003C1	2.6	1	1.6	1	SWMU	U
A039-1	039GW00101	37	5	2.9	5	SWMU	U
A039-2	039GW00201	42	5	2.9	4	SWMU	U
A039-3	039GW00301	2.5	5	2.9	5	SWMU	U
A039-4	039GW00401	47	5	2.9	5	SWMU	U
A039-5	039GW00501	71	5	2.9	5	SWMU	U
A039-6	039GW00604	3.9	2	4.1	2	SWMU	U
A039-7	039GW00704	—	—	3.2	3	SWMU	U
A039-8	039GW00804	8.0	4	3.7	4	SWMU	U
A039-9	039GW00904	27	4	3.7	4	SWMU	U
A039-10	039GW01004	23.5	3	3.9	3	SWMU	U
A039-11	039GW01104	4.0	4	3.2	3	SWMU	U
A039-12	039GW01204	111	4	3.6	4	SWMU	U
A039-13	039GW01301	5.6	4	3.7	3	SWMU	U
A039-14	039GW01401	29	4	4.7	3	SWMU	U
A039-15	039GW01501	5.2	4	3.4	3	SWMU	U
A039-16	039GW016C1	3.8	1	1.6	1	SWMU	U
A039-17	039GW017C1	8.9	1	1.6	1	SWMU	U
A039-18	039GW018C1	6.0	1	1.6	1	SWMU	U
A039-19	039GW019C1	16.3	1	1.6	1	SWMU	U
A042-1	042GW00101	2.4	5	2.9	5	SWMU	U
A042-2	042GW00201	2.6	5	2.9	5	SWMU	U
A042-3	042GW00301	4.4	5	2.9	5	SWMU	U
A043-1	043GW00101	22	3	5.5	2	SWMU	U
A505-1	505GW00101	5.7	4	2.9	5	AOC	U
A506-1	506GW00101	3.0	3	3.3	3	AOC	U
AGD-1	GDAGW00101	20.5	4	3.3	4	GRID	U
AGD-2	GDAGW00201	7.6	4	3.3	4	GRID	U
AGD-3	GDAGW00301	5.9	4	3.3	4	GRID	U

Appendix 1. Mean arsenic and thallium concentrations in water samples from wells at the Charleston Naval Complex, South Carolina—Continued

[µg/L, microgram per liter; GEOCODE, the depositional environment in which an upper surficial aquifer well is screened—U is upland soils, M is infilled marsh, and NA is not applicable to lower surficial aquifer wells; SWMU, solid-waste management unit; AOC, area of concern; FDS, fuel delivery system monitoring wells; GRID, regularly spaced wells throughout the Charleston Naval Complex; —, no data]

Well identifier	Well number	Mean arsenic concentration, in µg/L	Number of arsenic sampling events	Mean thallium concentration, in µg/L	Number of thallium sampling events	Well type	GEOCODE
Zone A, lower surficial aquifer							
A038-1D	038GW01D01	2.5	4	3.3	4	SWMU	NA
A039-4D	039GW04D01	2.5	5	2.9	5	SWMU	NA
A039-8D	039GW08D04	14	4	3.7	4	SWMU	NA
A039-9D	039GW09D06	1.7	3	3.9	3	SWMU	NA
A039-10D	039GW10D06	2.1	3	3.9	3	SWMU	NA
A039-12D	039GW12D04	1.7	3	3.7	3	SWMU	NA
A039-13D	039GW13D06	1.7	3	3.9	3	SWMU	NA
A039-14D	039GW14D01	2.0	4	3.8	4	SWMU	NA
A039-15D	039GW15D01	1.9	4	3.8	4	SWMU	NA
A039-16D	039GW16DC1	1.0	1	1.6	1	SWMU	NA
A039-17D	039GW17DC1	3.2	1	1.6	1	SWMU	NA
A039-18D	039GW18DC1	1.0	1	1.6	1	SWMU	NA
A039-19D	039GW19DC1	1.0	1	1.6	1	SWMU	NA
AGD-1D	GDAGW01D01	8.4	4	3.3	4	GRID	NA
AGD-2D	GDAGW02D01	7.5	4	16.3	4	GRID	NA
AGD-3D	GDAGW03D01	15.0	3	67.7	3	GRID	NA
Zone B, upper surficial aquifer							
BGD-1	NBCBGDB001	11.4	4	25.3	4	GRID	—
BGD-2	NBDBGDB002	3.8	4	12.3	4	GRID	—
BGD-3	NBCBGDB003	9.1	4	12.4	4	GRID	—
BGD-4	NBCBGDB004	2.8	4	3.4	4	GRID	—
Zone B, lower surficial aquifer							
BGD-1D	NBCBGDB01D	7.5	4	25.3	4	GRID	NA
BGD-4D	NBCBGDB04D	2.8	4	3.3	4	GRID	NA
Zone C, upper surficial aquifer							
C044-1	044GW00101	3.7	6	13.8	6	SWMU	M
C044-2	044GW00201	4.2	5	4.0	5	SWMU	M
C044-3	044GW00301	3.2	5	4.7	5	SWMU	U
C044-4	044GW00401	15.8	5	4.9	5	SWMU	M
C044-5	044GW00501	4.0	5	3.7	5	SWMU	M
C044-6	044GW00601	4.6	5	3.7	5	SWMU	M
C044-7	044GW00701	47.2	6	3.8	6	SWMU	M
C044-8	044GW00801	12.7	5	3.5	5	SWMU	M
C047-1	047GW00101	9.7	6	3.1	5	SWMU	U
C047-2	047GW00201	10.2	4	3.5	4	SWMU	U
C047-3	047GW00301	2.7	4	3.2	4	SWMU	U
C047-4	047GW00401	4.2	4	3.3	4	SWMU	U
C047-5	047GW00501	4.4	4	3.9	4	SWMU	U
C047-6	047GW00601	4.4	4	3.9	4	SWMU	U
C047-7	047GW00701	2.7	4	3.5	4	SWMU	U
C047-8	047GW00801	2.7	4	3.3	4	SWMU	U
C047-9	047GW00901	2.7	4	3.8	4	SWMU	U

Appendix 1. Mean arsenic and thallium concentrations in water samples from wells at the Charleston Naval Complex, South Carolina—Continued

[µg/L, microgram per liter; GEOCODE, the depositional environment in which an upper surficial aquifer well is screened—U is upland soils, M is infilled marsh, and NA is not applicable to lower surficial aquifer wells; SWMU, solid-waste management unit; AOC, area of concern; FDS, fuel delivery system monitoring wells; GRID, regularly spaced wells throughout the Charleston Naval Complex; —, no data]

Well identifier	Well number	Mean arsenic concentration, in µg/L	Number of arsenic sampling events	Mean thallium concentration, in µg/L	Number of thallium sampling events	Well type	GEOCODE
Zone C, upper surficial aquifer (Continued)							
C047-10	047GW01001	2.7	4	3.3	4	SWMU	U
C047-11	047GW01101	89.6	6	3.3	5	SWMU	U
C047-12	047GW01201	11.2	4	3.9	4	SWMU	U
C047-13	047GW01301	3.8	4	3.3	4	SWMU	U
C047-14	047GW01501	5.3	4	3.2	4	SWMU	U
C510-1	510GW00101	2.8	4	3.2	4	AOC	U
C510-2	510GW00201	2.8	4	3.2	4	AOC	U
C523-1	523GW00101	6.9	4	3.6	4	AOC	M
C523-2	523GW00201	17.3	4	3.6	4	AOC	M
C700-1	NBCC700001	6.4	1	2.3	1	AOC	M
CGD-1	NBCGDC001	3.3	4	3.5	4	GRID	U
CGD-2	NBCGDC002	6.6	4	3.2	4	GRID	U
Zone C, lower surficial aquifer							
CGD1D	GDCGW01D01	2.7	4	3.2	4	GRID	NA
CGD2D	GDCGW02D01	2.7	4	3.2	4	GRID	NA
Zone D, upper surficial aquifer							
DGD-1	GDDGW0101	3.2	4	4.6	4	GRID	—
Zone D, lower surficial aquifer							
DGD-1D	GDDGW01D1	4.1	4	5.0	4	GRID	NA
Zone E, upper surficial aquifer							
E018-1	018GW00101	3.4	4	3.5	4	SWMU	M
E018-2	018GW00201	3.4	4	3.5	4	SWMU	M
E021-1	021GW00101	3.8	2	4.8	2	SWMU	M
E021-2	021GW00201	22.8	2	3.9	2	SWMU	M
E021-3	021GW00301	3.1	4	4.0	4	SWMU	M
E023-1	023GW00101	3.6	4	3.9	4	SWMU	M
E025-1	025GW00101	3.1	4	3.5	4	SWMU	M
E025-2	025GW00201	3.1	4	3.3	4	SWMU	M
E025-3	025GW00301	3.8	4	4.2	4	SWMU	M
E025-4	025GW00401	3.3	4	3.7	4	SWMU	M
E053-1	053GW00101	9.6	4	4.6	4	SWMU	U
E054-1	054GW00101	3.8	2	3.9	2	SWMU	M
E054-2	054GW00201	3.5	4	4.6	4	SWMU	M
E054-3	054GW00301	5.1	2	3.9	2	SWMU	M
E063-1	063GW00101	4.9	4	4.5	4	SWMU	M
E063-2	063GW00201	7.2	4	4.6	4	SWMU	M
E065-1	065GW00101	5.4	4	4.3	4	SWMU	M
E065-2	065GW00201	7.6	4	3.9	4	SWMU	M
E065-3	065GW00301	11.0	4	3.9	4	SWMU	M
E065-4	065GW00401	17.5	4	3.9	4	SWMU	M
E065-5	065GW00501	16.8	4	4.1	4	SWMU	M
E065-6	065GW00601	3.2	4	4.0	4	SWMU	M

Appendix 1. Mean arsenic and thallium concentrations in water samples from wells at the Charleston Naval Complex, South Carolina—Continued

[µg/L, microgram per liter; GEOCODE, the depositional environment in which an upper surficial aquifer well is screened—U is upland soils, M is infilled marsh, and NA is not applicable to lower surficial aquifer wells; SWMU, solid-waste management unit; AOC, area of concern; FDS, fuel delivery system monitoring wells; GRID, regularly spaced wells throughout the Charleston Naval Complex; —, no data]

Well identifier	Well number	Mean arsenic concentration, in µg/L	Number of arsenic sampling events	Mean thallium concentration, in µg/L	Number of thallium sampling events	Well type	GEOCODE
Zone E, upper surficial aquifer (Continued)							
E065-7	065GW00701	5.2	4	4.6	4	SWMU	M
E065-8	065GW00801	21.9	2	4.5	4	SWMU	M
E067-1	067GW00103	10.7	2	3.9	2	SWMU	U
E067-2	067GW00203	2.3	4	4.5	2	SWMU	M
E070-1	070GW00101	3.5	4	4.2	4	SWMU	U
E070-2	070GW00201	3.4	4	3.9	4	SWMU	U
E083-1	083GW00101	31.5	4	3.9	4	SWMU	U
E083-2	083GW00201	8.5	4	3.3	4	SWMU	U
E084-1	084GW00101	3.1	4	3.3	4	SWMU	U
E084-2	084GW00201	41.2	4	4.7	4	SWMU	U
E097-1	097GW00101	19.2	4	3.6	4	SWMU	M
E100-1	100GW00101	17.2	4	3.5	4	SWMU	M
E102-1	102GW00101	5.4	4	3.4	4	SWMU	U
E106-1	106GW00101	35.3	4	3.5	4	SWMU	M
E145-1	145GW00103	2.5	2	2.7	2	SWMU	U
E145-2	145GW00203	6.4	2	2.7	2	SWMU	U
E145-3	145GW00303	2.7	2	4.1	2	SWMU	U
E172-1	172GW00101	5.5	4	3.4	4	SWMU	U
E172-2	172GW00201	9.4	4	3.3	4	SWMU	U
E525-1	525GW00101	5.4	4	3.9	4	AOC	U
E526-1	526GW00101	3.9	4	4.4	4	AOC	U
E526-2	526GW00201	6.2	4	3.9	4	AOC	U
E528-1	528GW00101	4.3	4	3.3	4	AOC	U
E530-1	530GW00101	12.4	4	3.7	4	AOC	U
E530-2	530GW00201	3.6	4	3.4	4	AOC	U
E538-1	538GW00101	59.2	4	4.1	4	AOC	U
E539-1	539GW00101	3.0	4	4.4	4	AOC	U
E542-1	542GW00101	3.0	4	4.0	4	AOC	U
E542-2	542GW00201	3.9	4	4.3	4	AOC	U
E542-3	542GW00301	3.9	4	4.2	4	AOC	U
E542-4	542GW00401	19.6	4	4.0	4	AOC	U
E543-1	543GW00101	3.8	4	3.9	4	AOC	M
E549-1	549GW00101	12.4	4	3.5	4	AOC	U
E549-2	549GW00201	5.1	4	3.9	4	AOC	U
E549-3	549GW00301	3.1	4	3.6	5	AOC	U
E550-1	550GW00101	46.9	5	4.2	4	AOC	M
E551-1	551GW00101	3.1	4	4.3	4	AOC	U
E551-2	551GW00201	3.2	4	3.9	4	AOC	M
E559-1	559GW00101	3.1	4	3.3	4	AOC	M
E559-2	559GW00201	3.1	4	3.4	4	AOC	M
E559-3	559GW00301	5.4	4	4.1	4	AOC	U
E559-4	559GW00401	15.7	4	4.7	4	AOC	M

Appendix 1. Mean arsenic and thallium concentrations in water samples from wells at the Charleston Naval Complex, South Carolina—Continued

[μg/L, microgram per liter; GEOCODE, the depositional environment in which an upper surficial aquifer well is screened—U is upland soils, M is infilled marsh, and NA is not applicable to lower surficial aquifer wells; SWMU, solid-waste management unit; AOC, area of concern; FDS, fuel delivery system monitoring wells; GRID, regularly spaced wells throughout the Charleston Naval Complex; —, no data]

Well identifier	Well number	Mean arsenic concentration, in μg/L	Number of arsenic sampling events	Mean thallium concentration, in μg/L	Number of thallium sampling events	Well type	GEOCODE
Zone E, upper surficial aquifer (Continued)							
E559-5	559GW00501	3.9	4	4.0	4	AOC	M
E563-1	563GW00101	32.3	4	3.3	4	AOC	M
E563-2	563GW00201	30.3	4	3.6	4	AOC	M
E563-3	563GW00301	3.3	4	3.7	4	AOC	U
E566-1	566GW00101	4.1	4	4.1	4	AOC	U
E569-1	569GW00101	3.1	4	3.5	4	AOC	U
E569-2	569GW00201	3.1	4	3.5	4	AOC	U
E570-1	570GW00101	2.5	4	3.2	4	AOC	U
E570-2	570GW00201	17.8	4	4.1	4	AOC	U
E570-3	570GW00301	3.1	4	3.3	4	AOC	U
E570-4	570GW00401	3.3	3	4.4	4	AOC	U
E572-1	572GW00101	9.6	4	5.4	4	AOC	U
E572-2	572GW00201	3.4	4	4.5	4	AOC	U
E572-3	572GW00301	4.4	4	4.6	4	AOC	U
E573-1	573GW00101	3.1	4	4.2	4	AOC	M
E574-1	574GW00101	4.3	4	3.5	4	AOC	U
E574-2	574GW00201	3.8	4	3.3	4	AOC	U
E574-3	574GW00301	12.3	4	3.3	4	AOC	U
E576-1	576GW00101	3.4	4	3.8	4	AOC	U
E576-2	576GW00201	3.5	4	3.9	4	AOC	U
E580-1	580GW00101	3.1	4	3.7	4	AOC	M
E580-2	580GW00201	10.6	4	4.4	4	AOC	U
E583-1	583GW00101	3.5	4	3.3	4	AOC	M
E583-2	583GW00201	3.3	4	4.4	4	AOC	M
E583-3	583GW00301	3.1	4	4.0	4	AOC	M
E586-1	586GW00101	18.4	4	3.3	4	AOC	M
E590-1	590GW00101	27.9	4	3.7	4	AOC	U
E596-1	596GW00101	14.1	4	4.0	4	AOC	M
E596-2	596GW00201	6.8	4	4.1	4	AOC	M
E596-3	596GW00301	26.4	4	5.3	4	AOC	U
E596-4	596GW00401	3.6	4	3.5	4	AOC	U
E598-1	598GW00101	22.1	4	5.2	4	AOC	M
E599-1	599GW00101	3.5	4	4.0	4	AOC	M
E605-1	605GW00101	9.9	4	3.5	4	AOC	M
E605-2	605GW00201	6.6	4	3.5	4	AOC	M
E605-3	605GW00301	65.6	4	3.5	4	AOC	M
FDS-18A	FDSGW18A01	5.0	2	4.6	2	FDS	M
EGD-1	GDEGW00101	12.0	4	4.5	4	GRID	M
EGD-2	GDEGW00201	285.3	4	3.7	4	GRID	M
EGD-3	GDEGW00301	50.4	4	3.5	4	GRID	M
EGD-4	GDEGW00401	5.8	5	3.9	5	GRID	M
EGD-5	GDEGW00501	3.1	4	4.9	4	GRID	M

Appendix 1. Mean arsenic and thallium concentrations in water samples from wells at the Charleston Naval Complex, South Carolina—Continued

[µg/L, microgram per liter; GEOCODE, the depositional environment in which an upper surficial aquifer well is screened—U is upland soils, M is infilled marsh, and NA is not applicable to lower surficial aquifer wells; SWMU, solid-waste management unit; AOC, area of concern; FDS, fuel delivery system monitoring wells; GRID, regularly spaced wells throughout the Charleston Naval Complex; –, no data]

Well identifier	Well number	Mean arsenic concentration, in µg/L	Number of arsenic sampling events	Mean thallium concentration, in µg/L	Number of thallium sampling events	Well type	GEOCODE
Zone E, upper surficial aquifer (Continued)							
EGD-6	GDEGW00601	13.6	4	3.9	4	GRID	U
EGD-7	GDEGW00701	3.2	4	3.5	4	GRID	U
EGD-8	GDEGW00801	85.7	4	4.8	4	GRID	M
EGD-9	GDEGW00901	10.4	4	3.3	4	GRID	M
EGD-10	GDEGW01001	5.7	4	4.9	4	GRID	M
EGD-11	GDEGW01101	8.1	4	4.1	4	GRID	M
EGD-12	GDEGW01201	3.3	4	3.8	4	GRID	M
EGD-13	GDEGW01301	3.3	4	3.8	4	GRID	U
EGD-14	GDEGW01401	21.2	4	3.5	4	GRID	M
EGD-15	GDEGW01501	9.6	4	3.9	4	GRID	M
EGD-16	GDEGW01601	61.3	4	4.9	4	GRID	U
EGD-17	GDEGW01701	4.1	4	3.8	4	GRID	M
EGD-18	GDEGW01801	7.7	4	3.0	4	GRID	U
EGD-19	GDEGW01901	4.0	4	4.4	4	GRID	U
EGD-20	GDEGW02001	3.1	4	3.3	4	GRID	M
EGD-21	GDEGW02101	4.7	4	4.1	4	GRID	M
EGD-22	GDEGW02201	4.0	4	3.5	4	GRID	M
EGD-23	GDEGW02301	3.2	4	4.0	4	GRID	M
EGD-24	GDEGW02401	4.0	4	3.4	4	GRID	M
EGD-25	GDEGW02501	3.4	4	3.3	4	GRID	M
EGD-26	GDEGW02601	4.5	4	4.4	4	GRID	M
EGD-27	GDEGW02701	14.6	4	4.5	4	GRID	U
EGD-28	GDEGW02801	2.9	4	5.0	4	GRID	U
EGD-29	GDEGW02901	14.2	4	4.4	4	GRID	M
EGD-30	GDEGW03001	3.0	4	3.9	4	GRID	U
Zone E, lower surficial aquifer							
E023-1D	023GW01D01	3.3	4	3.9	4	SWMU	NA
E065-4D	065GW04D01	25.9	4	3.9	4	SWMU	NA
E070-1D	070GW01D01	7.9	4	8.7	5	SWMU	NA
E106-1D	106GW01D01	3.4	4	4.5	4	SWMU	NA
E145-1D	145GW01D03	72.1	2	8.0	2	SWMU	NA
E172-2D	172GW02D01	26.2	4	3.8	4	SWMU	NA
E526-1D	526GW01D01	3.2	4	3.9	4	AOC	NA
E530-1D	530GW01D01	2.4	4	3.6	4	AOC	NA
E530-2D	530GW02D01	2.5	4	3.7	4	AOC	NA
E538-1D	538GW01D01	4.5	4	4.2	4	AOC	NA
E539-1D	539GW01D01	3.0	4	3.9	4	AOC	NA
E551-2D	551GW02D01	21.1	4	3.3	4	AOC	NA
E559-2D	559GW02D01	3.2	4	2.9	4	AOC	NA
E559-3D	559GW03D01	4.0	4	3.4	4	AOC	NA
E559-4D	559GW04D01	16.5	4	3.7	4	AOC	NA
E563-1D	563GW01D01	4.4	4	3.3	4	AOC	NA

Appendix 1. Mean arsenic and thallium concentrations in water samples from wells at the Charleston Naval Complex, South Carolina—Continued

[µg/L, microgram per liter; GEOCODE, the depositional environment in which an upper surficial aquifer well is screened—U is upland soils, M is infilled marsh, and NA is not applicable to lower surficial aquifer wells; SWMU, solid-waste management unit; AOC, area of concern; FDS, fuel delivery system monitoring wells; GRID, regularly spaced wells throughout the Charleston Naval Complex; —, no data]

Well identifier	Well number	Mean arsenic concentration, in µg/L	Number of arsenic sampling events	Mean thallium concentration, in µg/L	Number of thallium sampling events	Well type	GEOCODE
Zone E, lower surficial aquifer (Continued)							
E566-1D	566GW01D01	69.7	4	3.9	4	AOC	NA
E569-1D	569GW01D01	3.9	4	3.4	4	AOC	NA
E570-2D	570GW02D01	3.3	4	4.8	4	AOC	NA
E570-3D	570GW03D01	2.5	4	2.7	4	AOC	NA
E573-1D	573GW01D01	3.6	4	3.6	4	AOC	NA
E574-1D	574GW01D01	72.9	4	5.0	4	AOC	NA
E576-2D	576GW02D01	41.9	4	3.6	4	AOC	NA
E580-1D	580GW01D01	97.4	4	4.4	4	AOC	NA
E583-2D	583GW02D01	15.2	4	4.7	4	AOC	NA
E590-1D	590GW01D01	3.8	4	4.0	4	AOC	NA
E596-1D	596GW01D01	39.0	4	3.6	4	AOC	NA
E596-4D	596GW04D01	10.4	4	4.4	4	AOC	NA
EGD-1D	GDEGW01D01	3.4	4	4.5	4	GRID	NA
EGD-2D	GDEGW02D01	3.7	4	4.1	4	GRID	NA
EGD-3D	GDEGW03D01	3.3	4	4.8	4	GRID	NA
EGD-4D	GDEGW04D01	3.5	4	4.8	4	GRID	NA
EGD-5D	GDEGW05D01	4.5	4	4.1	4	GRID	NA
EGD-6D	GDEGW06D01	3.5	4	3.7	4	GRID	NA
EGD-7D	GDEGW07D01	44.6	4	3.9	4	GRID	NA
EGD-8D	GDEGW08D01	3.3	4	4.7	4	GRID	NA
EGD-9D	GDEGW09D01	79.3	5	4.0	5	GRID	NA
EGD-10D	GDEGW10D01	3.3	4	4.5	4	GRID	NA
EGD-11D	GDEGW11D01	5.2	4	5.4	4	GRID	NA
EGD-12D	GDEGW12D01	13.5	4	3.5	4	GRID	NA
EGD-13D	GDEGW13D01	6.8	4	3.8	4	GRID	NA
EGD-14D	GDEGW14D01	8.6	4	4.4	4	GRID	NA
EGD-15D	GDEGW15D01	34.9	4	3.9	4	GRID	NA
EGD-16D	GDEGW16D01	10.4	4	3.8	4	GRID	NA
EGD-17D	GDEGW17D01	7.1	4	3.5	4	GRID	NA
EGD-18D	GDEGW18D01	2.5	4	2.7	4	GRID	NA
EGD-19D	GDEGW19D01	3.1	4	4.8	4	GRID	NA
EGD-20D	GDEGW20D01	3.1	4	3.3	4	GRID	NA
EGD-21D	GDEGW21D01	3.1	4	3.7	4	GRID	NA
EGD-22D	GDEGW22D01	3.3	4	3.8	4	GRID	NA
EGD-23D	GDEGW23D01	3.4	4	4.7	4	GRID	NA
EGD-24D	GDEGW24D01	11.1	4	4.9	4	GRID	NA
EGD-25D	GDEGW25D01	3.6	4	4.5	4	GRID	NA
EGD-26D	GDEGW26D01	2.3	4	5.0	4	GRID	NA
EGD-27D	GDEGW27D01	2.2	4	4.8	4	GRID	NA
EGD-28D	GDEGW28D01	4.7	4	4.9	4	GRID	NA
EGD-29D	GDEGW29D01	35.2	4	4.9	4	GRID	NA
EGD-30D	GDEGW30D01	4.5	4	4.4	4	GRID	NA

Appendix 1. Mean arsenic and thallium concentrations in water samples from wells at the Charleston Naval Complex, South Carolina—Continued

[µg/L, microgram per liter; GEOCODE, the depositional environment in which an upper surficial aquifer well is screened—U is upland soils, M is infilled marsh, and NA is not applicable to lower surficial aquifer wells; SWMU, solid-waste management unit; AOC, area of concern; FDS, fuel delivery system monitoring wells; GRID, regularly spaced wells throughout the Charleston Naval Complex; —, no data]

Well identifier	Well number	Mean arsenic concentration, in µg/L	Number of arsenic sampling events	Mean thallium concentration, in µg/L	Number of thallium sampling events	Well type	GEOCODE
Zone F, upper surficial aquifer							
F109-1	109GW00101	2.2	4	4.6	4	SWMU	M
F109-2	109GW00201	3.3	1	2.3	1	SWMU	M
F240-3	240GW00301	12.3	4	6.1	4	SWMU	M
F607-1	607GW00101	2.2	2	5.0	4	AOC	U
F607-2	607GW00201	5.9	4	4.4	4	AOC	U
F607-3	607GW00301	3.2	4	4.7	4	AOC	U
F607-4	607GW00401	65.3	4	4.8	4	AOC	U
F607-6	607GW00601	2.5	4	4.9	4	AOC	U
F607-7	607GW00701	6.8	4	4.8	4	AOC	U
F607-8	607GW008A2	2.3	3	5.0	3	AOC	U
F607-9	607GW009A1	33.0	4	3.7	4	AOC	U
F609-1	609GW00101	7.5	1	2.3	1	AOC	M
F609-2	609GW00201	105.0	1	2.3	1	AOC	M
F613-1	613GW00101	2.2	4	6.3	4	AOC	M
F613-3	613GW00301	7.0	4	5.3	4	AOC	M
F613-4	613GW00401	4.8	4	5.2	4	AOC	M
F613-5	613GW00501	29.0	4	6.0	4	AOC	U
F613-6	613GW00601	27.3	1	1.6	1	AOC	M
F617-1	617GW00101	15.8	4	4.4	4	AOC	M
F617-2	617GW002A1	3.1	4	9.0	4	AOC	M
F617-3	617GW00301	3.3	1	2.3	1	AOC	M
F619-1	619GW00101	5.5	4	5.1	4	AOC	M
F619-2	619GW00201	5.9	4	4.5	4	AOC	M
F619-3	619GW00301	4.8	4	5.9	4	AOC	M
F620-1	620GW00101	6.9	4	6.9	4	AOC	M
F620-2	620GW00201	4.5	4	4.5	4	AOC	M
F620-3	620GW003A1	4.5	4	5.0	4	AOC	M
F620-4	620GW004A1	7.5	4	4.9	4	AOC	M
FGD-1	GDFGW00101	5.6	4	5.0	4	GRID	M
GEL-5	GELGW00501	9.1	4	4.4	4	AOC	M
GEL-6	GELGW00601	2.2	4	4.5	4.	AOC	M
GEL-7	GELGW00701	28.0	4	5.6	4	AOC	U
GEL-8	GELGW00801	8.6	4	5.5	4	AOC	U
GEL-11	GELGW01101	7.0	4	5.6	4	AOC	U
GEL-12	GELGW01201	2.3	4	4.4	4	AOC	—
GEL-13	GELGW01301	11.8	4	4.8	4	AOC	U
GEL-14	GELGW01401	41.4	5	3.3	5	AOC	—
SME-1	SMEGW00101	47.4	4	4.8	4	AOC	M
SME-3	SMEGW00301	5.8	4	4.9	4	AOC	M
SME-4	SMEGW00401	18.0	4	5.2	4	AOC	M
SME-5	SMEGW00501	47.8	4	4.3	4	AOC	M
SME-6	SMEGW00601	45.2	4	5.7	4	AOC	M

Appendix 1. Mean arsenic and thallium concentrations in water samples from wells at the Charleston Naval Complex, South Carolina—Continued

[µg/L, microgram per liter; GEOCODE, the depositional environment in which an upper surficial aquifer well is screened—U is upland soils, M is infilled marsh, and NA is not applicable to lower surficial aquifer wells; SWMU, solid-waste management unit; AOC, area of concern; FDS, fuel delivery system monitoring wells; GRID, regularly spaced wells throughout the Charleston Naval Complex; —, no data]

Well identifier	Well number	Mean arsenic concentration, in µg/L	Number of arsenic sampling events	Mean thallium concentration, in µg/L	Number of thallium sampling events	Well type	GEOCODE
Zone F, upper surficial aquifer (Continued)							
SME-7	SMEGW00701	3.0	4	5.5	4	AOC	M
SME-8	SMEGW00801	25.7	4	4.8	4	AOC	M
FDS-16A	FDSGW16A01	11.0	2	3.9	2	FDS	U
FDS-16B	FDSGW16B01	109.0	3	4.8	3	FDS	U
FDS-16C	FDSGW16C01	7.8	2	5.2	2	FDS	U
FDS-17A	FDSGW17A01	6.8	3	3.3	3	FDS	M
FDS-17B	FDSGW17B01	57.8	3	3.2	3	FDS	M
Zone F, lower surficial aquifer							
F607-1D	607GW01D01	7.5	4	4.8	4	AOC	NA
F607-2D	607GW02D01	13.6	4	4.4	4	AOC	NA
F607-3D	607GW03D01	14.2	4	4.6	4	AOC	NA
F607-4D	607GW04D01	3.0	4	5.0	4	AOC	NA
F607-5D	607GW05D01	2.5	4	4.5	4	AOC	NA
F607-6D	607GW06DA2	2.1	3	4.9	3	AOC	NA
F613-2D	613GW02D01	5.1	4	4.9	4	AOC	NA
GDF-1D	GDFGW01D01	8.8	4	5.6	4	GRID	NA
Zone G, upper surficial aquifer							
G003-1	003GW00101	3.8	5	4.8	5	SWMU	U
G003-2	003GW00201	2.6	5	4.7	5	SWMU	U
G003-3	003GW00301	4.1	5	4.7	5	SWMU	U
G006-1	006GW00101	3.9	4	5.5	4	SWMU	M
G006-2	006GW00201	4.4	4	4.9	4	SWMU	M
G006-3	006GW00301	339.0	4	6.6	4	SWMU	M
G006-4	006GW00401	14.0	4	6.7	4	SWMU	M
G006-5	006GW00501	3.8	4	5.1	4	SWMU	M
G006-6	006GW00601	9.4	4	4.4	4	SWMU	M
G006-7	006GW00701	11.0	4	5.2	4	SWMU	M
G008-1	008GW00101	5.8	4	4.4	4	SWMU	M
G008-2	008GW00201	2.3	4	4.7	4	SWMU	M
G008-3	008GW00301	10.8	4	5.0	4	SWMU	M
G008-4	008GW00401	5.1	4	5.3	4	SWMU	M
G008-5	008GW00501	4.9	4	4.6	4	SWMU	M
G008-6	008GW00601	22.8	4	4.4	4	SWMU	M
G011-1	011GW00101	3.2	4	4.4	4	SWMU	U
G011-2	011GW00201	4.2	4	4.5	4	SWMU	U
G011-3	011GW00301	31.1	4	4.4	4	SWMU	U
G024-1	024GW00101	69.4	3	3.9	3	SWMU	U
G024-2	024GW00201	5.4	3	4.0	3	SWMU	U
G024-3	024GW00301	12.9	3	4.6	3	SWMU	U
G024-4	024GW00401	5.0	3	3.9	3	SWMU	M
G120-1	120GW00101	47.0	4	4.4	4	SWMU	M
G120-2	120GW00201	6.0	4	4.4	4	SWMU	M

Appendix 1. Mean arsenic and thallium concentrations in water samples from wells at the Charleston Naval Complex, South Carolina—Continued

[µg/L, microgram per liter; GEOCODE, the depositional environment in which an upper surficial aquifer well is screened—U is upland soils, M is infilled marsh, and NA is not applicable to lower surficial aquifer wells; SWMU, solid-waste management unit; AOC, area of concern; FDS, fuel delivery system monitoring wells; GRID, regularly spaced wells throughout the Charleston Naval Complex; —, no data]

Well identifier	Well number	Mean arsenic concentration, in µg/L	Number of arsenic sampling events	Mean thallium concentration, in µg/L	Number of thallium sampling events	Well type	GEOCODE
Zone G, upper surficial aquifer (Continued)							
G120-3	120GW00301	40.7	4	4.4	4	SWMU	M
G636-1	636GW00101	6.1	4	4.4	4	AOC	M
G637-1	637GW00101	5.9	4	4.5	4	AOC	M
G637-2	637GW002A1	2.4	4	5.0	4	AOC	M
G637-3	637GW003A1	5.8	5	5.0	4	AOC	M
G638-1	638GW00101	6.0	4	4.8	4	AOC	M
G706-1	706GW001A1	9.6	4	6.0	4	AOC	U
FDS-1A	FDSGW01A01	4.6	2	3.9	2	FDS	M
FDS-1B	FDSGW01B01	7.8	2	3.9	2	FDS	M
FDS-1C	FDSGW01C01	7.1	2	3.9	2	FDS	M
FDS-1D	FDSGW01D01	3.5	2	6.9	2	FDS	M
FDS-1E	FDSGW01E01	4.0	2	3.9	2	FDS	M
FDS-2A	FDSGW02A01	11.2	2	5.4	2	FDS	M
FDS-2B	FDSGW02B01	8.6	2	3.9	2	FDS	M
FDS-2C	FDSGW02C01	13.2	2	5.1	2	FDS	M
FDS-3A	FDSGW03A01	5.1	2	4.7	2	FDS	M
FDS-3B	FDSGW03B01	5.7	2	4.0	2	FDS	M
FDS-3C	FDSGW03C01	4.6	2	5.4	2	FDS	M
FDS-4A	FDSGW04A01	4.3	2	4.8	2	FDS	M
FDS-4B	FDSGW04B01	2.6	2	3.9	2	FDS	M
FDS-4C	FDSGW04C01	2.3	2	5.6	2	FDS	M
FDS-5A	FDSGW05A01	4.6	2	4.6	2	FDS	M
FDS-5B	FDSGW05B01	2.3	2	5.3	2	FDS	M
FDS-6A	FDSGW06A01	9.3	2	3.9	2	FDS	M
FDS-6B	FDSGW06B01	2.4	2	4.5	2	FDS	M
FDS-6C	FDSGW06C01	28.1	2	4.6	2	FDS	M
FDS-7A	FDSGW07A01	9.0	2	5.0	2	FDS	M
FDS-7B	FDSGW07B01	4.6	2	6.5	2	FDS	M
FDS-7C	FDSGW07C01	7.8	2	8.4	2	FDS	M
FDS-7D	FDSGW07D01	8.1	2	7.2	2	FDS	M
FDS-8A	FDSGW08A01	18.5	2	4.6	2	FDS	U
FDS-8B	FDSGW08B01	6.6	2	6.8	2	FDS	U
FDS-8C	FDSGW08C01	2.8	2	7.0	2	FDS	U
FDS-9A	FDSGW09A01	3.7	2	7.4	2	FDS	M
FDS-9B	FDSGW09B01	4.6	2	3.9	2	FDS	M
FDS-9C	FDSGW09C01	4.0	2	5.0	2	FDS	M
FDS-10A	FDSGW10A01	5.9	2	6.9	2	FDS	M
FDS-10B	FDSGW10B01	2.3	2	3.9	2	FDS	M
FDS-10C	FDSGW10C01	2.3	2	3.9	2	FDS	M
FDS-11A	FDSGW11A01	2.5	2	3.9	2	FDS	M
FDS-11B	FDSGW11B01	2.3	2	3.9	2	FDS	M
FDS-11C	FDSGW11C01	2.7	2	3.9	2	FDS	M

Appendix 1. Mean arsenic and thallium concentrations in water samples from wells at the Charleston Naval Complex, South Carolina—Continued

[µg/L, microgram per liter; GEOCODE, the depositional environment in which an upper surficial aquifer well is screened—U is upland soils, M is infilled marsh, and NA is not applicable to lower surficial aquifer wells; SWMU, solid-waste management unit; AOC, area of concern; FDS, fuel delivery system monitoring wells; GRID, regularly spaced wells throughout the Charleston Naval Complex; —, no data]

Well identifier	Well number	Mean arsenic concentration, in µg/L	Number of arsenic sampling events	Mean thallium concentration, in µg/L	Number of thallium sampling events	Well type	GEOCODE
Zone G, upper surficial aquifer (Continued)							
FDS-12A	FDSGW12A01	14.6	2	4.7	2	FDS	U
FDS-12B	FDSGW12B01	38.7	2	4.1	2	FDS	U
FDS-13A	FDSGW13A01	118.5	2	5.4	2	FDS	M
FDS-13B	FDSGW13B01	11.0	2	6.8	2	FDS	M
FDS-13C	FDSGW13C01	5.0	2	3.9	2	FDS	M
FDS-13D	FDSGW13D01	9.6	2	4.6	2	FDS	M
FDS-13E	FDSGW13E01	26.2	2	4.5	2	FDS	M
FDS-14A	FDSGW14A01	36.1	2	4.3	2	FDS	M
FDS-14B	FDSGW14B01	14.7	2	4.1	2	FDS	M
FDS-14C	FDSGW14C01	19.5	2	5.2	2	FDS	M
FDS-15A	FDSGW15A01	23.1	2	4.0	2	FDS	U
FDS-15B	FDSGW15B01	4.4	2	3.9	2	FDS	U
FDS-15C	FDSGW15C01	2.3	2	4.5	2	FDS	U
GGD-1	GDGGW00102	121.0	4	4.7	4	GRID	M
GGD-2	GDGGW00201	21.7	4	5.2	4	GRID	U
Zone G, lower surficial aquifer							
GGD-1D	GDGGW01D01	2.4	4	5.1	4	GRID	NA
GGD-2D	GDGGW02D01	41.9	4	4.7	4	GRID	NA
Zone H, upper surficial aquifer							
HMW4	009GFMW401	5.0	3	6.8	3	SWMU	M
H009-1	009GW00101	2.1	4	3.6	4	SWMU	U
H009-2	009GW00201	2.7	4	4.8	4	SWMU	M
H009-3	009GW00301	9.3	4	3.8	4	SWMU	M
H009-4	009GW00401	11.0	4	32.6	5	SWMU	M
H009-5	009GW00501	14.0	4	15.7	4	SWMU	M
H009-6	009GW00601	4.8	4	6.1	4	SWMU	U
H009-7	009GW00701	4.2	4	6.2	4	SWMU	M
H009-8	009GW00801	40.9	4	16.3	4	SWMU	M
H009-9	009GW00901	7.9	4	2.3	4	SWMU	M
H009-10	009GW01001	10.7	4	15.0	4	SWMU	M
H009-11	009GW01101	34.5	4	6.0	4	SWMU	M
H009-12	009GW01201	43.2	4	6.1	4	SWMU	M
H009-13	009GW01301	3.9	4	6.4	4	SWMU	M
H009-14	009GW01401	20.0	4	16.0	4	SWMU	M
H009-15	009GW01501	9.2	4	6.5	4	SWMU	U
H009-16	009GW01601	4.7	3	6.2	3	SWMU	U
H009-17	009GW01701	2.2	3	4.1	3	SWMU	M
H009-18	009GW01801	2.7	3	4.4	3	SWMU	M
H009-19	009GW01901	2.5	3	4.1	3	SWMU	M
H009-20	009GW02001	17.8	1	3.1	1	SWMU	U
H009-21	009GW02101	17.8	1	3.1	1	SWMU	U
H009-22	009GW02201	20.5	1	3.1	1	SWMU	U

Appendix 1. Mean arsenic and thallium concentrations in water samples from wells at the Charleston Naval Complex, South Carolina—Continued

[µg/L, microgram per liter; GEOCODE, the depositional environment in which an upper surficial aquifer well is screened—U is upland soils, M is infilled marsh, and NA is not applicable to lower surficial aquifer wells; SWMU, solid-waste management unit; AOC, area of concern; FDS, fuel delivery system monitoring wells; GRID, regularly spaced wells throughout the Charleston Naval Complex; —, no data]

Well identifier	Well number	Mean arsenic concentration, in µg/L	Number of arsenic sampling events	Mean thallium concentration, in µg/L	Number of thallium sampling events	Well type	GEOCODE
Zone H, upper surficial aquifer (Continued)							
H009-23	009GW02301	21.6	1	3.1	1	SWMU	U
H009-24	009GW02401	2.9	1	3.1	1	SWMU	M
H009-25	009GW02501	10.8	1	10.0	1	SWMU	M
H009-26	009GW02601	2.9	1	7.9	1	SWMU	M
H009-27	009GW02701	4.1	1	3.1	1	SWMU	M
H009-28	009GW02801	4.7	1	3.6	1	SWMU	M
H009-29	009GW02901	3.7	1	3.8	1	SWMU	M
H009-30	009GW03001	2.9	1	3.1	1	SWMU	M
H009-121	009GW12101	2.3	3	5.4	3	SWMU	M
H013-1301	013G130101	4.1	4	3.7	4	SWMU	M
H013-1302	013G130202	3.4	3	3.3	3	SWMU	M
H013-1	013GW00101	11.5	4	4.1	4	SWMU	M
H013-2	013GW00201	3.2	4	3.7	4	SWMU	M
H013-3	013GW00301	3.8	4	3.7	4	SWMU	M
H013-4	013GW00401	4.1	4	3.7	4	SWMU	M
H013-5	013GW00501	3.4	4	3.8	4	SWMU	M
H013-6	013GW00601	3.6	4	3.7	4	SWMU	M
H013-7	013GW00701	2.7	4	4.1	4	SWMU	M
H014-1	014GW00102	7.7	3	5.6	4	SWMU	M
H014-2	014GW00201	4.8	4	3.3	4	SWMU	M
H014-3	014GW00301	6.9	4	2.4	4	SWMU	M
H014-4	014GW00401	3.0	4	2.4	4	SWMU	M
H014-5	014GW00501	8.7	4	2.5	4	SWMU	M
H017-1	017GW00101	7.1	4	3.0	4	SWMU	M
H017-2	017GW00201	5.2	4	3.1	4	SWMU	M
H017-3	017GW00301	4.4	4	3.0	4	SWMU	M
H017-4	017GW00401	4.3	4	3.0	4	SWMU	M
H017-5	017GW00501	2.4	3	2.9	3	SWMU	M
H017-6	017GW00601	2.8	3	2.8	3	SWMU	M
H121-1	121GW00104	2.5	1	3.0	3	SWMU	M
H136-1	136GW00101	11.2	4	4.1	4	SWMU	M
H178-1	178GW00101	4.6	4	2.7	4	SWMU	M
H178-2	178GW00201	6.4	5	2.8	4	SWMU	M
H653-1	653GW00101	41.5	4	2.5	4	FDS	M
H653-2	653GW00201	16.2	4	2.5	4	FDS	M
H653-3	653GW00302	6.5	2	3.1	1	FDS	M
H655-1	655GW00101	5.5	7	4.0	5	FDS	M
H655-2	655GW00201	12.4	7	3.7	5	FDS	M
H655-3	655GW00301	29.1	6	3.2	5	FDS	M
H656-1	656GW00101	11.9	5	3.9	5	FDS	M
H656-2	656GW00201	3.4	4	3.5	4	FDS	M
H656-3	656GW00301	5.4	4	8.4	4	FDS	M

Appendix 1. Mean arsenic and thallium concentrations in water samples from wells at the Charleston Naval Complex, South Carolina—Continued

[µg/L, microgram per liter; GEOCODE, the depositional environment in which an upper surficial aquifer well is screened—U is upland soils, M is infilled marsh, and NA is not applicable to lower surficial aquifer wells; SWMU, solid-waste management unit; AOC, area of concern; FDS, fuel delivery system monitoring wells; GRID, regularly spaced wells throughout the Charleston Naval Complex; —, no data]

Well identifier	Well number	Mean arsenic concentration, in µg/L	Number of arsenic sampling events	Mean thallium concentration, in µg/L	Number of thallium sampling events	Well type	GEOCODE
Zone H, upper surficial aquifer (Continued)							
H660-1	660GW00101	3.0	4	3.0	4	FDS	M
H660-2	660GW00201	7.6	4	2.8	4	FDS	M
H662-1	662GW00101	3.0	4	3.1	4	FDS	M
H662-2	662GW00201	2.8	4	3.0	4	FDS	M
H663-1	663GW00101	6.7	4	3.0	4	FDS	M
H663-2	663GW00201	6.8	4	3.0	4	FDS	M
H666-1	666GW00101	4.3	4	4.0	4	FDS	M
H666-2	666GW00201	2.2	4	2.9	4	FDS	M
H667-1	667GW00101	2.2	4	4.0	4	FDS	M
H667-2	667GW00201	12.2	4	4.6	4	FDS	M
HGD-1	GDHGW00101	6.7	4	2.4	4	GRID	M
HGD-2	GDHGW00201	12.2	4	16.7	4	GRID	M
HGD-3	GDHGW00301	36.6	7	5.5	5	GRID	M
HGD-4	GDHGW00401	3.8	4	3.1	4	GRID	M
HGD-5	GDHGW00501	9.5	4	5.6	4	GRID	M
HGD-6	GDHGW00601	25.4	7	2.9	5	GRID	M
HGD-7	GDHGW00701	3.7	4	2.3	4	GRID	M
HGD-8	GDHGW00801	2.1	4	2.2	4	GRID	M
HGD-9	GDHGW00901	7.3	4	29.8	4	GRID	M
HGD-10	GDHGW01001	3.3	4	6.2	4	GRID	M
HGD-11	GDHGW01101	14.1	4	4.1	4	GRID	M
GEL-15	GELGW01502	327.0	1	8.3	1	SWMU	M
Zone H, lower surficial aquifer							
H009-1D	009GW01D01	3.6	1	3.1	1	SWMU	NA
H009-2D	009GW02D01	5.6	4	6.6	5	SWMU	NA
H009-3D	009GW03D01	2.8	4	4.9	4	SWMU	NA
H009-4D	009GW04D01	4.7	4	44.6	4	SWMU	NA
H009-5D	009GW05D01	12.1	4	15.0	4	SWMU	NA
H009-6D	009GW06D01	13.2	4	18.0	4	SWMU	NA
H009-7D	009GW07D01	4.8	4	8.4	4	SWMU	NA
H009-8D	009GW08D01	2.7	4	15.5	4	SWMU	NA
H009-12D	009GW12D01	20.6	4	2.4	4	SWMU	NA
H009-23D	009GW23D01	2.9	1	3.1	1	SWMU	NA
H009-24D	009GW24D01	54.6	1	3.1	1	SWMU	NA
H009-25D	009GW25D01	2.9	1	3.1	1	SWMU	NA
H009-26D	009GW26D01	12.0	1	5.5	1	SWMU	NA
H014-1D	014GW01D01	4.0	4	8.1	4	SWMU	NA
H014-2D	014GW02D01	4.0	4	6.1	4	SWMU	NA
H014-3D	014GW03D01	7.6	4	6.3	4	SWMU	NA
H014-4D	014GW04D01	5.5	4	7.4	4	SWMU	NA
H014-5D	014GW05D01	4.7	4	9.6	4	SWMU	NA
HGD-1D	GDHGW01D1	11.1	4	15.8	4	GRID	NA

Appendix 1. Mean arsenic and thallium concentrations in water samples from wells at the Charleston Naval Complex, South Carolina—Continued

[µg/L, microgram per liter; GEOCODE, the depositional environment in which an upper surficial aquifer well is screened—U is upland soils, M is infilled marsh, and NA is not applicable to lower surficial aquifer wells; SWMU, solid-waste management unit; AOC, area of concern; FDS, fuel delivery system monitoring wells; GRID, regularly spaced wells throughout the Charleston Naval Complex; —, no data]

Well identifier	Well number	Mean arsenic concentration, in µg/L	Number of arsenic sampling events	Mean thallium concentration, in µg/L	Number of thallium sampling events	Well type	GEOCODE
Zone H, lower surficial aquifer (Continued)							
HGD-2D	GDHGW02D1	1.9	4	14.3	4	GRID	NA
HGD-3D	GDHGW03D0	3.4	7	4.2	5	GRID	NA
HGD-4D	GDHGW04D1	2.3	4	6.5	4	GRID	NA
HGD-5D	GDHGW05D1	2.9	4	6.4	4	GRID	NA
HGD-6D	GDHGW06D1	3.8	7	5.2	5	GRID	NA
HGD-7D	GDHGW07D1	2.8	4	4.7	4	GRID	NA
HGD-8D	GDHGW08D1	2.0	4	4.6	4	GRID	NA
HGD-9D	GDHGW09D1	2.3	4	4.4	4	GRID	NA
HGD-10D	GDHGW10D1	3.5	4	4.6	4	GRID	NA
HGD-11D	GDHGW11D1	3.1	4	4.7	4	GRID	NA
Zone I, upper surficial aquifer							
I012-1	012GW00102	5.3	4	3.8	4	SWMU	M
I012-2	012GW00202	165.9	5	3.7	5	SWMU	M
I012-3	012GW00302	4.3	4	4.2	4	SWMU	M
I177-1	177GW00102	3.6	3	2.4	3	SWMU	M
I177-2	177GW00202	3.0	3	2.4	3	SWMU	M
I671-1	671GW00102	7.6	3	5.2	3	AOC	M
I671-2	671GW00202	5.3	3	4.2	3	AOC	M
I671-3	671GW00302	31.7	4	4.9	4	AOC	M
I671-4	671GW00402	9.9	3	4.2	3	AOC	M
I675-1	675GW00102	4.2	3	4.2	3	AOC	M
I675-2	675GW00202	5.7	3	4.2	3	AOC	M
I676-1	676GW00102	4.2	3	4.7	3	AOC	M
I677-2	677GW00202	7.4	3	4.9	3	AOC	M
I678-1	678GW00102	6.4	3	4.2	3	AOC	M
I678-2	678GW00202	5.8	3	4.2	3	AOC	M
I679-1	679GW00101	5.8	2	2.4	2	AOC	M
I680-1	680GW00102	51.8	1	1.8	1	AOC	M
I680-2	680GW00202	3.1	1	1.8	1	AOC	M
I680-3	680GW00302	.9	1	1.8	1	AOC	M
I681-1	681GW00101	7.8	3	2.3	3	AOC	M
I681-2	681GW00201	3.5	3	2.3	3	AOC	M
I681-3	681GW00301	4.0	3	2.4	3	AOC	M
I687-1	687GW00102	3.7	6	4.1	6	AOC	M
I687-2	687GW00202	55.7	6	3.7	6	AOC	M
I687-3	687GW00302	4.5	6	3.7	6	AOC	M
I687-4	687GW00402	4.7	6	3.7	6	AOC	M
IGD-1	GDIGW00102	9.3	3	5.6	3	GRID	M
IGD-2	GDIGW00202	9.2	3	4.3	3	GRID	M
IGD-3	GDIGW00302	4.0	4	3.2	4	GRID	M
IGD-4	GDIGW00402	19.6	3	4.2	3	GRID	M
IGD-5	GDIGW00502	3.3	3	3.6	3	GRID	M

Appendix 1. Mean arsenic and thallium concentrations in water samples from wells at the Charleston Naval Complex, South Carolina—Continued

[µg/L, microgram per liter; GEOCODE, the depositional environment in which an upper surficial aquifer well is screened—U is upland soils, M is infilled marsh, and NA is not applicable to lower surficial aquifer wells; SWMU, solid-waste management unit; AOC, area of concern; FDS, fuel delivery system monitoring wells; GRID, regularly spaced wells throughout the Charleston Naval Complex; —, no data]

Well identifier	Well number	Mean arsenic concentration, in µg/L	Number of arsenic sampling events	Mean thallium concentration, in µg/L	Number of thallium sampling events	Well type	GEOCODE
Zone I, upper surficial aquifer (Continued)							
IGD-6	GDIGW00602	5.2	3	5.4	5	GRID	M
IGD-7	GDIGW00702	3.7	5	5.4	5	GRID	M
IGD-8	GDIGW00802	5.2	6	3.7	6	GRID	M
IGD-9	GDIGW00902	24.1	3	5.1	3	GRID	M
IGD-10	GDIGW01002	6.2	3	4.2	3	GRID	M
IGD-11	GDIGW01102	4.6	3	4.7	3	GRID	M
IGD-12	GDIGW01202	4.2	4	4.5	3	GRID	M
IGD-13	GDIGW01302	19.7	4	3.6	4	GRID	M
IGD-14	GDIGW01402	9.9	3	4.2	3	GRID	M
IGD-15	GDIGW01502	4.2	3	4.2	3	GRID	M
IGD-16	GDIGW01602	4.2	3	4.2	3	GRID	M
IGD-17	GDIGW01702	48.7	3	4.4	3	GRID	M
IGD-18	GDIGW01802	4.2	3	4.2	3	GRID	M
IGD-19	GDIGW01902	14.9	3	4.2	3	GRID	M
Zone I, lower surficial aquifer							
IGD-1D	GDIGW01D02	4.2	3	5.1	3	GRID	NA
IGD-2D	GDIGW02D02	3.3	3	4.0	3	GRID	NA
IGD-3D	GDIGW03D02	4.2	4	3.8	4	GRID	NA
IGD-4D	GDIGW04D02	5.8	3	4.2	3	GRID	NA
IGD-5D	GDIGW05D02	3.3	3	3.6	3	GRID	NA
IGD-6D	GDIGW06D02	3.7	3	3.5	3	GRID	NA
IGD-7D	GDIGW07D02	4.4	5	6.0	5	GRID	NA
IGD-8D	GDIGW08D02	3.5	6	5.0	6	GRID	NA
IGD-9D	GDIGW09D02	4.2	3	4.9	3	GRID	NA
IGD-10D	GDIGW10D02	6.0	3	5.6	3	GRID	NA
IGD-11D	GDIGW11D02	5.3	3	5.2	3	GRID	NA
IGD-12D	GDIGW12D02	4.2	3	4.4	3	GRID	NA
IGD-13D	GDIGW13D02	4.7	3	5.4	4	GRID	NA
IGD-14D	GDIGW14D02	4.2	3	4.2	3	GRID	NA
IGD-15D	GDIGW15D02	4.2	3	4.9	3	GRID	NA
IGD-16D	GDIGW16D02	4.2	3	4.2	3	GRID	NA
IGD-17D	GDIGW17D02	9.4	4	7.5	4	GRID	NA
IGD-18D	GDIGW18D02	4.4	4	4.9	4	GRID	NA
IGD-19D	GDIGW19D02	11.2	3	4.2	3	GRID	NA

Appendix 2. Arsenic concentrations in Shipyard Creek marsh sediment samples from core SYC-1 at the Charleston Naval Complex, South Carolina

[BLS, below land surface; kg, kilogram; mg/L, milligram per liter; mg/kg, milligram per kilogram (dry sample); —, not available]

Depth, in inches BLS	Mass, in kg	Arsenic, in mg/L	Arsenic, in mg/kg	Depth, in inches BLS	Mass, in kg	Arsenic, in mg/L	Arsenic, in mg/kg
10.6	0.002011	—	—	45.3	0.002522	0.134	2.7
11.4	.002060	0.120	2.9	46.1	.002582	.177	3.4
12.2	.001055	.110	5.2	46.9	.002524	.264	5.2
13.0	.002024	.130	3.2	47.6	.002520	.225	4.5
13.8	.002022	—	—	48.4	.002545	.226	4.4
14.6	.002453	.178	3.6	49.2	.002540	.145	2.9
15.4	.002114	.179	4.2	50.0	.002501	.390	7.8
16.1	.002017	.137	3.4	50.8	.002569	.253	4.9
16.9	.002016	.120	3.0	51.6	.002523	.170	3.4
17.7	.002046	.117	2.9	52.4	.002502	.143	2.9
18.5	.002020	.105	2.6	53.1	.002517	.125	2.5
19.3	.002014	.098	2.4	53.9	.002513	.136	2.7
20.1	.002075	.101	2.4	54.7	.002501	.182	3.6
20.9	.002269	.116	2.6	55.5	.002514	.158	3.0
21.7	.002038	.095	2.3	56.3	.002511	.153	3.0
22.4	.002416	.087	1.8	57.1	.002038	.128	3.1
23.2	.002043	.084	2.1	57.9	.002008	.147	3.7
24.0	.002020	.087	2.2	58.7	.002047	.121	3.0
24.8	.002035	.092	2.3	59.4	.002021	.110	2.7
25.6	.002026	.092	2.3	60.2	.002025	.116	2.9
26.4	.002020	.084	2.1	61.0	.002055	.160	3.9
27.2	.002080	.094	2.3	61.8	.002043	.110	2.7
28.0	.002003	.144	3.6	62.6	.002003	.110	2.7
28.7	.002005	.147	3.7	63.4	.002001	.115	2.9
29.5	.002022	.140	3.5	64.2	.002027	.132	3.3
30.3	.002072	.135	3.3	65.0	.002024	.106	2.6
31.1	.002014	.219	5.4	65.7	.002008	.139	3.5
31.9	.002005	.149	3.7	66.5	.002017	.122	3.0
32.7	.002008	.114	2.8	67.3	.002023	.135	3.3
33.5	.002037	.125	3.1	68.1	.001960	.114	2.9
34.3	.002500	.124	2.5	68.9	.002003	.110	2.7
35.0	.002533	.151	3.0	69.7	.002065	.110	2.7
35.8	.002517	.159	3.2	70.5	.002095	.121	2.9
36.6	.002509	.180	3.6	71.3	.002020	.118	2.9
37.4	.002561	.145	2.8	72.0	.002002	.093	2.3
38.2	.002495	.143	2.9	72.8	.002013	.085	2.1
39.0	.002541	.166	3.3	73.6	.002065	.082	2.0
39.8	.002580	.154	3.0	74.4	.002011	.105	2.6
40.6	.002593	.110	2.1	75.2	.002014	.091	2.3
41.3	.002524	.171	3.4	76.0	.001984	.114	2.9
42.1	.002504	.071	1.4	76.8	.002035	.093	2.3
42.9	.002539	.200	3.9	77.6	.002093	.104	2.5
43.7	.002583	.206	4.0	78.3	.002048	.068	1.7
44.5	.002543	.122	2.4	79.1	.002017	.083	2.1

Appendix 2. Arsenic concentrations in Shipyard Creek marsh sediment samples from core SYC-1 at the Charleston Naval Complex, South Carolina—Continued

[BLS, below land surface; kg, kilogram; mg/L, milligram per liter; mg/kg, milligram per kilogram (dry sample); —, not available]

Depth, in inches BLS	Mass, in kg	Arsenic, in mg/L	Arsenic, in mg/kg
79.9	0.002026	0.073	1.8
80.7	.002073	.085	2.1
81.5	.002044	.110	2.7
82.3	.002014	.131	3.3
83.1	.002025	.116	2.9
83.9	.002078	.095	2.3
84.6	.002025	.095	2.3
85.4	.002003	.101	2.5
86.2	.002010	.087	2.2
87.0	.002011	.094	2.3
87.8	.002100	.090	2.1
88.6	.002021	.091	2.3
89.4	.001996	.104	2.6
90.2	.002007	.078	1.9
90.9	.002018	.082	2.0
91.7	.001994	.101	2.5
92.5	.002011	.072	1.8
93.3	.002052	.115	2.8
94.1	.002002	.063	1.6
94.9	.002056	.068	1.7
95.7	.002008	.101	2.5
96.5	.002070	.098	2.4
97.2	.002036	.098	2.4
98.0	.002002	.061	1.5
98.8	.001632	.082	2.5
99.6	.002027	.074	1.8
100.4	—	—	—
101.2	.002004	.085	2.1
102.0	.001469	.094	3.2
102.8	.002010	.101	2.5
103.5	.002034	.093	2.3
104.3	.002244	.075	1.7
105.1	.002190	.098	2.2
105.9	.002183	.117	2.7
106.7	.002146	.136	3.2
107.5	.002170	.126	2.9
108.3	.002023	.099	2.4
109.1	.002066	.116	2.8
109.8	.002046	.102	2.5
110.6	0.002085	0.108	2.6
111.4	.002025	.098	2.4
112.2	.002199	.128	2.9
113.0	.002182	.122	2.8
113.8	.002144	.134	3.1
114.6	.002077	.170	4.1
115.4	.002069	.187	4.5
116.1	.002126	.141	3.3
116.9	.002085	.153	3.7
118.5	.002086	.164	3.9
120.1	.002041	.095	2.3
121.7	.002030	.133	3.3
122.4	.002020	.171	4.2
123.2	.002013	.169	4.2
124.0	.002040	.153	3.8
124.8	.002017	.185	4.6
125.6	.002014	.184	4.6
126.4	.002029	.189	4.7
127.2	.002000	.178	4.5
128.0	.002055	—	—
128.7	.002032	.194	4.8
129.5	.002033	.167	4.1
130.3	.002014	.160	4.0
131.1	.002000	—	—
131.9	.002063	.156	3.8
132.7	.002086	.166	4.0
133.5	.002039	.178	4.4
134.3	.002000	.144	3.6
135.0	.002014	.118	2.9
135.8	.002105	.131	3.1
136.6	.002023	.166	4.1
137.4	.002000	.170	4.3
138.2	.002021	.129	3.2
139.0	.002000	.189	4.7
139.8	.002022	.173	4.3
140.6	.002000	.143	3.6
141.3	.002069	.141	3.4
142.9	.002039	.137	3.4

☆ U.S. GOVERNMENT PRINTING OFFICE: 2002 — 573-096 / 58023 Region No. 8

USGS

Mirecki and Falls

Magnitude and Extent of Arsenic and Thallium Concentrations in Ground Water and Sediments at the Charleston Naval Complex, North Charleston, South Carolina, 1994–99

USGS WRIR-02-4226