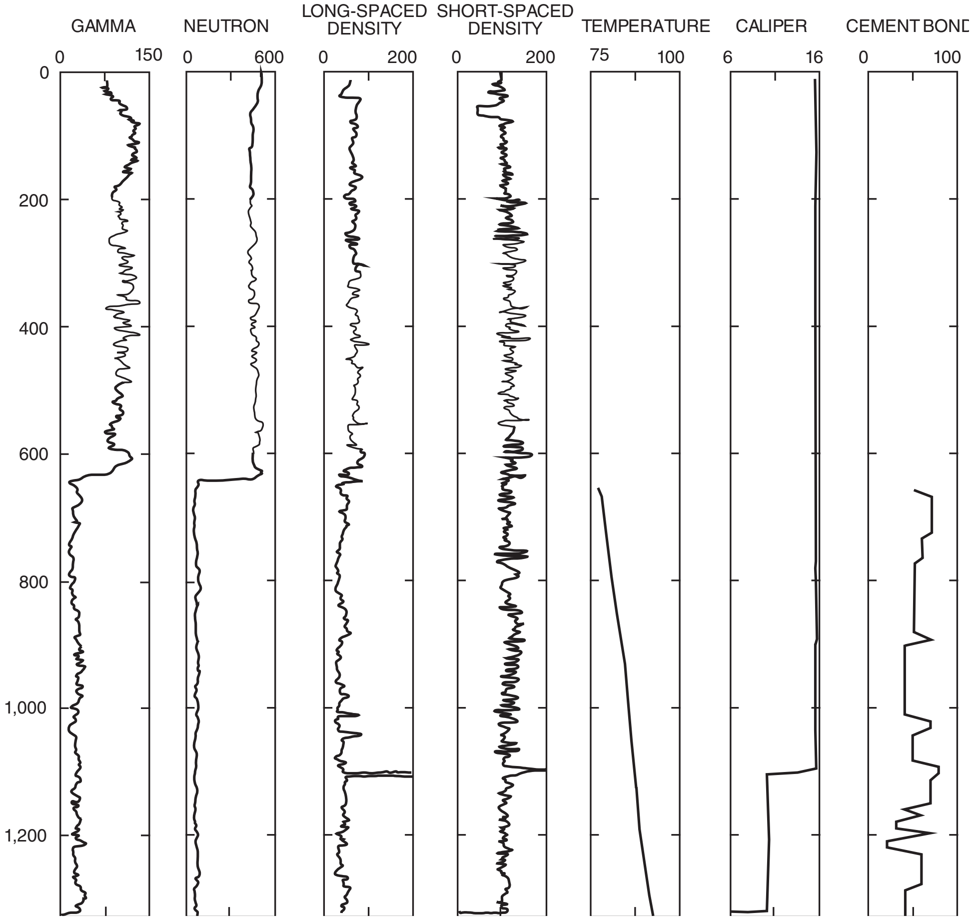
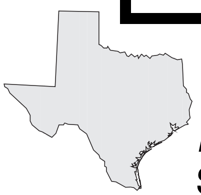
INTEGRITY OF PRODUCTION WELLS AND CONFINING UNIT AT THE NAVAL WEAPONS INDUSTRIAL RESERVE PLANT, DALLAS, TEXAS, 1995

U.S. GEOLOGICAL SURVEY
Water-Resources Investigations Report 97–4047





Prepared in cooperation with the
SOUTHERN DIVISION NAVAL FACILITIES
ENGINEERING COMMAND

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

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By S.A. Jones and Frederick L. Paillet

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Austin, Texas
1997

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VERTICAL DATUM AND ACRONYMS

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

Acronyms:

CRQL, contract required quantitation limit
DCE, dichloroethylene

DNAPL, dense nonaqueous phase liquid
E/A&H, EnSafe/Allen & Hoshall

LNAPL, light nonaqueous phase liquid
NWIRP, Naval Weapons Industrial Reserve Plant

PCB, polychlorinated biphenyl
PI, plasticity index

PQL, practical quantitation limit
RCRA, Resource Conservation and Recovery Act

RFI, RCRA facility investigation
SOUTHDIV, Southern Division Naval Facilities Engineering Command

SMCL, secondary maximum contaminant level
SVOC, semivolatile organic compound

TCE, trichloroethylene
tics, tentatively identified compounds

TPH, total petroleum hydrocarbon
USGS, U.S. Geological Survey

VC, vinyl chloride
VOC, volatile organic compound

Integrity of Production Wells and Confining Unit at the Naval Weapons Industrial Reserve Plant, Dallas, Texas, 1995

By S.A. Jones *and* Frederick L. Paillet

Abstract

Ground water in the shallow alluvial aquifer is contaminated at the Naval Weapons Industrial Reserve Plant, Dallas, Texas. Five production wells at the site are cased through the alluvial aquifer and underlying units and are screened in either the Paluxy or Twin Mountains aquifers. Three abandoned wells, originally completed in the Twin Mountains aquifer but filled with drilling mud in 1958, also penetrate the alluvial aquifer. The Paluxy and Twin Mountains aquifers are used for drinking-water supplies in and around the Dallas-Fort Worth metroplex.

Trichloroethylene and its degradation products, dichloroethylene and vinyl chloride, and the metal chromium previously have been detected in the shallow alluvial aquifer. Current (1995) analyses of water-quality samples taken from the static water column of the five production wells and one of the abandoned wells indicate no trichloroethylene, dichloroethylene, or vinyl chloride in the water column of these wells. Chromium was detected in all samples, but concentrations were less than the practical quantitation limit, which is the regulatory action level for this site.

The results of borehole geophysical log analysis indicate that two of the production wells could have vertically connected intervals where cement bonding in the well annulus is poor. The other production wells have overall good bonding. Temperature logs do not indicate flow behind casing except in the screened interval of one well. Geophysical logs show the Eagle Ford Shale ranges from 147 to 185 feet thick at the site. The Eagle Ford Shale has low permeability and a high plasticity index. These physical characteristics make the Eagle Ford Shale an excellent confining unit.

INTRODUCTION

A Resource Conservation and Recovery Act (RCRA) facility investigation (RFI) is being conducted by the Department of the Navy, Southern Division Naval Facilities Engineering Command (SOUTHDIV), at the Naval Weapons Industrial Reserve Plant (NWIRP) site in Dallas, Texas. The 314-acre NWIRP facility began operation in 1941 and has manufactured military and commercial aircraft since that time. The facility is government-owned, and the current contract operator is Northrup Grumman. Vought Aircraft operated the facility from 1948 to 1994. Manufacturing processes associated with the facility's operations include metal machining and treating; fabrication, painting, and stripping of aircraft or aircraft parts; and aircraft renovation. These processes create wastes that include oils and fuels, construction debris, and metals. Previous work by EnSafe/Allen & Hoshall (E/A&H), the consultant conducting the RFI, indicated the presence of trichloroethylene (TCE), dichloroethylene (DCE), vinyl chloride (VC), chromium, and other industrial-related contaminants in the shallow alluvial aquifer (1993 to present).

The U.S. Geological Survey (USGS) began a study in 1995 in cooperation with SOUTHDIV to determine if contaminants in the shallow alluvial aquifer have migrated, or have the potential to migrate, to deeper aquifers (Paluxy and Twin Mountains) through the deep production wells or poor confining units at the NWIRP. The Paluxy and Twin Mountains aquifers are the primary aquifers used for public water supply in north-central Texas. Five production wells open to the Paluxy or Twin Mountains aquifer and three abandoned wells at the NWIRP pass through the shallow alluvial aquifer and the bedrock confining unit (Eagle Ford Shale). The abandoned wells originally were completed in the Twin Mountains aquifer but were filled with drilling mud in 1958. These wells pass through areas that are in or near contaminant plumes in the shallow alluvial aquifer and are possible conduits for migration of contaminants to the Paluxy and Twin Mountains aquifers.

Purpose and Scope

The purpose of this report is to assess the integrity of the five production- and three abandoned-well casings and the surrounding cement that penetrate the shallow alluvial aquifer to the underlying Paluxy and Twin Mountains aquifers and to assess the integrity of the confining unit in preventing downward contaminant migration.

In April 1995 water samples from the five production wells were collected for analysis of volatile organic compounds (VOCs); semivolatile organic compounds (SVOCs); pesticides and polychlorinated biphenyls (PCBs); total petroleum hydrocarbons (TPHs); trace elements and major ions; cyanide; and field properties. Floating oil bailed from four of the five production wells was analyzed to determine if the oil was the same as that used to lubricate the turbine pumps. One of three abandoned wells had standing water in the casing, which was sampled for VOCs, trace elements, and major ions.

Geophysical logs, run in April and October 1995, for the five production and three abandoned wells were studied for indications of breaks or gaps in the well casings and cement around the casings. Temperature, caliper, borehole video, neutron, natural gamma, gamma-gamma, and acoustic signature logs were run in the wells as a part of the study. Resistivity logs run prior to the study in the boreholes of three of the five production wells before casings were set were provided by the NWIRP contract operator.

Description of Study Area

The study area is in the city of Dallas, Dallas County, in north-central Texas (fig. 1). The climate in the area is characterized by long, hot summers and short, mild winters. The mean temperature and precipitation for 1993 was 65.4 °F (degrees Fahrenheit) and 32.8 in. (inches), respectively (National Oceanic and Atmospheric Administration, 1993).

The 314-acre NWIRP facility is located west of the Naval Air Station Dallas, north of Mountain Creek Lake, and south and east of commercial and industrial areas. The land surface of the area generally is flat with a few human-made topographic highs. Land-surface altitudes range from 502 to 460 ft (feet) above sea level west to east; and from 496 to 462 ft above sea level north to south.

Acknowledgments

The authors acknowledge the cooperation and assistance of E/A&H with this project. E/A&H coordinated the removal of the turbine pumps, provided their onsite facilities for USGS use, and assisted with packaging and shipping of laboratory samples. The cooperation of Northrup Grumman, the contract operator at the NWIRP also is acknowledged, for allowing access to the site, providing assistance in the field, and providing historical information on the production wells. The USGS logging crew from the New Mexico District Office provided invaluable service with both the geophysical logging and collection of water-quality samples.

HYDROGEOLOGIC UNITS

The hydrogeologic units present in the study area are the shallow alluvial aquifer, the Eagle Ford Shale confining unit, the Woodbine aquifer, the Washita and Fredericksburg confining units, the Paluxy aquifer, the Glen Rose confining unit, and the Twin Mountains aquifer (fig. 2; table 1). The uppermost aquifer is the Woodbine, but because none of the production wells at the NWIRP are open to the Woodbine, it is not discussed in this report. The Washita, Fredericksburg, and Glen Rose confining units also are not described in this report.

Shallow Alluvial Aquifer

The shallow alluvial aquifer in the vicinity of the NWIRP ranges from about 12 to 75 ft thick. EnSafe/Allen & Hoshall (1994) identified three distinct water-yielding zones in the shallow alluvial aquifer separated by two thin, silty clay layers. The clay layers are discontinuous and the water-yielding zones are hydraulically connected in the southern and eastern parts of the study area near Mountain Creek Lake. The water-yielding zones range from 1 to 10 ft thick. Pumping of more than 20 wells produced 1.5 to 2.0 gal/min (gallons per minute) of sustained flow from each well. TCE and other chlorinated hydrocarbons have been detected in all three zones (EnSafe/Allen & Hoshall, 1994).

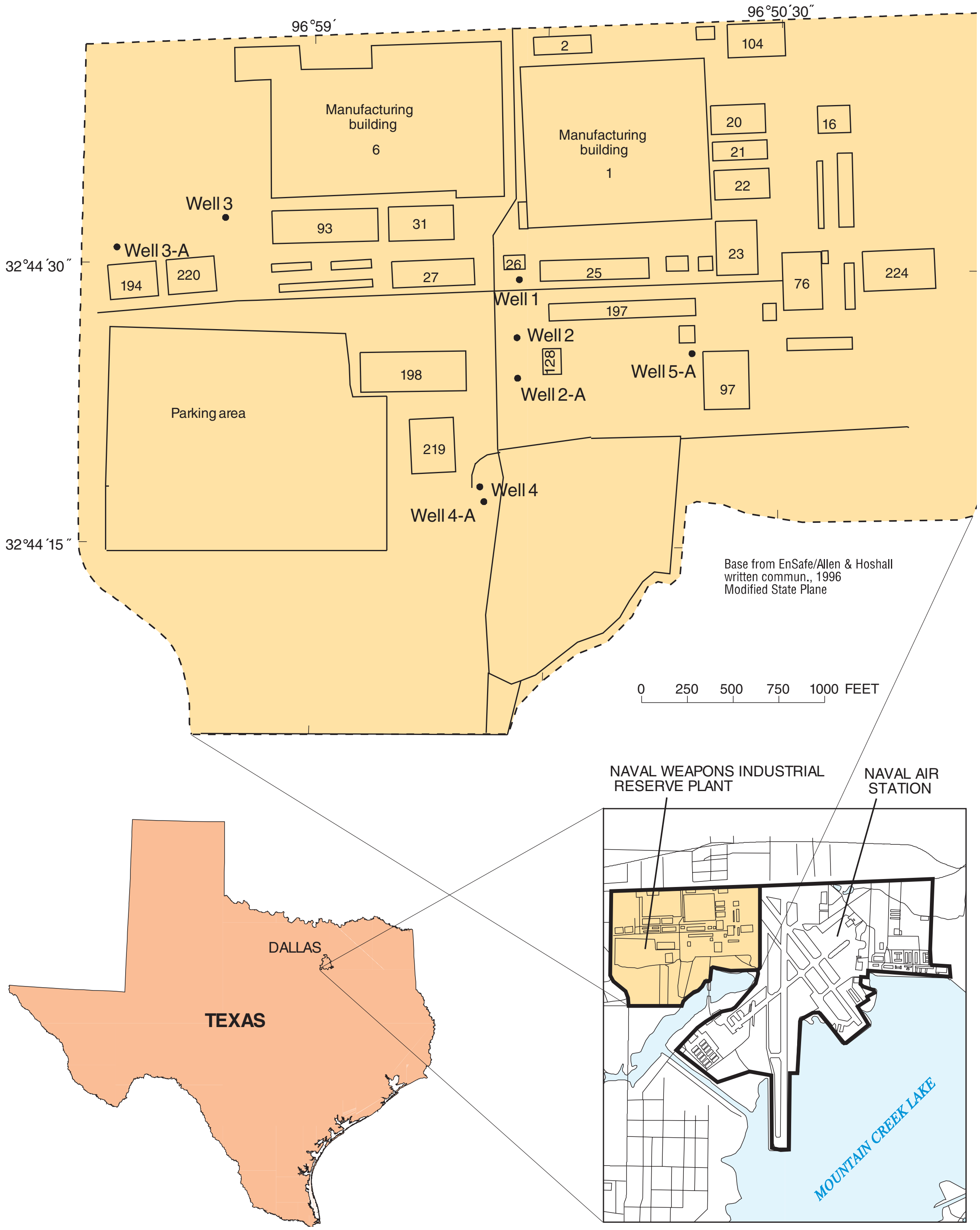
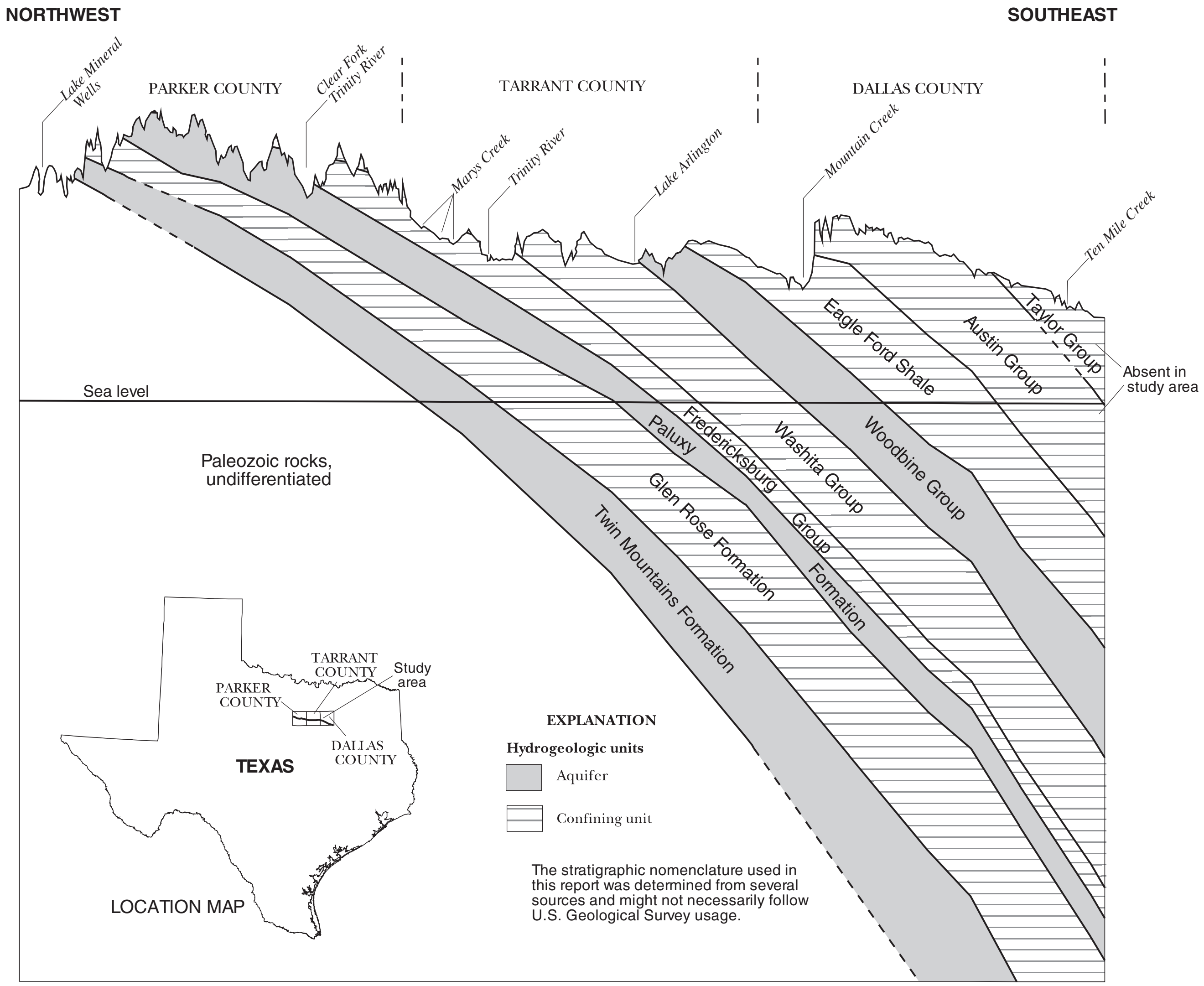


Figure 1. Location of study area and wells at the Naval Weapons Industrial Reserve Plant, Dallas, Texas.



The stratigraphic nomenclature used in this report was determined from several sources and might not necessarily follow U.S. Geological Survey usage.

NOT TO SCALE

Figure 2. Generalized section of north-central Texas showing geologic and hydrogeologic units.

Confining Unit

The Eagle Ford Shale is the bedrock confining unit directly underlying the shallow alluvial aquifer. Data collected during geophysical logging by the USGS and from historical well logs indicate the thickness of the confining unit in the study area ranges from 147 to 185 ft. The Eagle Ford Shale is a marine deposit that is mainly bluish-black laminated shale composed of the clay minerals calcium montmorillonite and kaolinite (Surles, 1987).

Deep Aquifers

Three major aquifers underlie the confining unit at the NWIRP site. The uppermost aquifer is the Woodbine; below the Woodbine and separated from it by a confining unit composed of the Washita and Fredericksburg Groups is the Paluxy; and below the Paluxy and separated from it by a confining unit composed of the Glen Rose Formation is the Twin Mountains aquifer. The Woodbine aquifer is not discussed in this report.

Paluxy Aquifer

The Paluxy Formation comprises the upper member of the Trinity Group and is one of the primary aquifers in north-central Texas. Composed mainly of fine- to coarse-grained white quartz sands interbedded with sandy, silty, calcareous, or waxy clay and shale, the Paluxy Formation is about 100 ft thick in the study area. The formation dips to the east at 30 feet per mile (ft/mi)

Table 1. Geologic units and their water-yielding characteristics

[Units of interest are shaded. All thicknesses except the alluvial deposit and Twin Mountains Formation are based on geophysical logs run by the U.S. Geological Survey at the Naval Weapons Industrial Reserve Plant and historical geophysical logs from Schlumberger (Jay Spence, Vought Aircraft, written commun., 1995); alluvial deposit thickness from EnSafe/Allen & Hoshall, 1994; Twin Mountains Formation thickness from Nordstrom (1982). The stratigraphic nomenclature used in this report was determined from several sources and might not necessarily follow U.S. Geological Survey usage.]

Era	System	Series/Group	Stratigraphic unit	Thickness (feet)	Hydrogeologic unit and water-yielding characteristics[1]
Cenozoic	Quaternary	Holocene	Alluvial deposit	12–75	Shallow alluvial aquifer Yields small quantities of water to wells
		Pleistocene			
Mesozoic	Cretaceous	Gulfian/ Navarro	Kemp Clay Corsicana Marl Nacatoch Sand	Absent in study area	
		Gulfian/ Taylor	Marlbrook Marl Pecan Gap Chalk Wolfe City-Ozan Formations	Absent in study area	
		Gulfian/ Austin	Gober Chalk Brownstown Marl Blossom Sand Bonham Formation	Absent in study area	
		Gulfian/ Eagle Ford Shale	Arcadia Park Shale	0–50	Eagle Ford Shale confining unit
			Britton Clay	130–165	
			Tarrant Sandy Clay	15–20	
		Gulfian/ Woodbine		240–265	Woodbine aquifer Yields moderate to large quantities of water
		Comanchean/ Washita		360–375	Washita/Fredericksburg confining unit
		Comanchean/ Fredericksburg		155–160	
		Comanchean/ Trinity	Paluxy Formation	95–105	Paluxy aquifer Yields small to moderate quantities of water
			Glen Rose Formation	550–555	Glen Rose confining unit
			Twin Mountains Formation	500–600	Twin Mountains aquifer Yields moderate to large quantities of water
Paleozoic			Paleozoic rocks undifferentiated		Paleozoic rock Not known to yield water in this area

[1] From Nordstrom (1982).

near the outcrop in Parker County and increases to 80 ft/mi near a freshwater/saline-water transition zone in southeastern Dallas County (Nordstrom, 1982).

Recharge to the aquifer primarily is from precipitation on the outcrop. Ground-water flow generally is from west to east, but a cone of depression north and south of the Dallas-Fort Worth metroplex causes local variations in the direction of flow (Baker and others, 1990). At the NWIRP, the Paluxy aquifer is confined by rocks of the overlying Fredericksburg and Washita Groups and by rocks of the underlying Glen Rose Formation. Average transmissivity and permeability for the Paluxy aquifer in north-central Texas has been reported as 500 ft^2/d (feet squared per day) and 7 ft/d (feet per day), respectively (Nordstrom, 1982). Transmissivity ranging from 670 to 800 ft^2/d and permeability ranging

Table 2. Well data for production and abandoned wells at the Naval Weapons Industrial Reserve Plant, Dallas, Texas

[Depth is in feet below land surface. --, no data]

Production wells

Well number	Aquifer	Year drilled	Original well depth (feet)	First screen depth (feet)	Top casing diameter (inches)	Water-quality sample collected
1	Paluxy	1940	1,180	974	10	Yes
2A	Twin Mountains	1957	2,148	1,965	16	Yes
3A	Twin Mountains	1957	2,066	2,040	16	Yes
4A	Twin Mountains	1957	2,081	2,065	16	Yes
5A	Twin Mountains	1967	2,105	--	16	Yes

Abandoned wells

Well number	Aquifer	Year drilled	Original well depth (feet)	Depth to mud (feet)	Top casing diameter (inches)	Water-quality sample collected
2	Twin Mountains	1941	2,148	120	16	Yes
3	Twin Mountains	1942	2,080	117	16	No
4	Twin Mountains	1942	2,077	114	16	No

from 2 to 16 ft/d (with an average of 7 ft/d) for the Paluxy aquifer in Dallas and Tarrant Counties has been reported by Nath (1983).

A comparison of regional maps of Paluxy aquifer water levels from 1955 and 1976 shows a decrease in water levels over the 20-year period, especially near the Euless area of Fort Worth in Tarrant County (Nordstrom, 1982). A map of water-level changes for the period 1976 to 1989 shows that water-level declines have slowed for the Dallas-Fort Worth metroplex and areas of decline have migrated to the north and south during the 13-year period (Baker and others, 1990). Well 1 at the NWIRP is open to the Paluxy aquifer (fig. 1, table 2). When the well was drilled in 1940, the static water level was 167 ft below land surface. Two water-level measurements in 1995 indicate that the water level had declined about 280 to 340 ft in 55 years; or about 5.6 ft/yr (feet per year).

Twin Mountains Aquifer

The Twin Mountains Formation[1] is the lower member of the Trinity Group. Composed mainly of medium- to coarse-grained sands, red and gray silty clays, and siliceous conglomerates of chert, quartzite, and quartz pebbles, the Twin Mountains Formation is about 500 ft thick in the study area. The formation dips to the east at 30 ft/mi near the outcrop in Parker County and the dip increases to 95 ft/mi near the fresh-water/saline-water transition zone in southeastern Dallas County (Nordstrom, 1982).

Recharge to the aquifer primarily is from precipitation on the outcrop, and ground-water movement is estimated to be less than 2 ft/yr (Nordstrom, 1982). Ground-water flow generally is from west to east, but a ground-water high, just north of the Dallas-Fort Worth metroplex, causes local variations in the direction of flow (Baker and others, 1990). The Twin Mountains aquifer is confined at the NWIRP by the rocks of the overlying Glen Rose Formation and underlying Paleozoic rocks. Average transmissivity and permeability for the Twin Mountains aquifer in Dallas County has been reported as 1,700 ft^2/d and 11 ft/d, respectively (Nordstrom, 1982). Slightly higher transmissivity (2,500 to 2,700 ft^2/d) and variable permeability (4 to 40 ft/d with an average of 7 ft/d) for wells in Dallas and Tarrant Counties has been reported by Nath (1983).

In eastern Tarrant and western Dallas Counties, water-level declines in the Twin Mountains aquifer

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[1] The stratigraphic nomenclature used in this report was determined from several sources and might not necessarily follow USGS usage.

averaged more than 20 ft/yr from 1955 to 1976 (Nordstrom, 1982). A map of water-level changes for the period 1976 to 1989 shows that water-levels in the Mountain Creek Lake area have declined about 100 to 150 ft during the 13-year period (Baker and others, 1990). Wells 2A, 3A, 4A, and 5A at the NWIRP are open to the Twin Mountains aquifer (fig.1, table 2); historical water-level data are available for two of them. The static water levels in wells 2A and 3A were about 580 ft below land surface in 1957 and declined about 50 and 70 ft, respectively, from 1957 to 1995. The average rates of decline were about 1.3 and 1.8 ft/yr, respectively, over the 38-year period.

METHODS OF DATA COLLECTION AND ANALYSIS

Basic data for the five production wells and the three abandoned wells are listed in table 2. The three abandoned wells were filled in 1958 with drilling mud, which has settled over 100 ft since that time. There are no historical records indicating why these wells were abandoned.

Water-Quality Sampling

Water-quality samples were collected from wells 1, 2, 2A, 3A, 4A, and 5A at the NWIRP during April 12–18, 1995, to determine if contaminants from the shallow alluvial aquifer were present in the water column of the wells. The five production wells (1, 2A, 3A, 4A, and 5A) were sampled for VOCs, SVOCs, pesticides, PCBs, TPHs, trace elements, major ions, cyanide, and physical properties. The constituents and the contract required quantitation limit (CRQL) for each of these groups, except physical properties, are listed in table 3. The CRQL is the reporting limit for the contract laboratory (Robert Meierer, Compuchem Environmental Corp., written commun., 1995). The abandoned well (2) was sampled for VOCs, trace elements, and major ions. The five production wells were sampled at selected depth intervals in the water column because of the physical characteristics of the contaminants of concern in the shallow alluvial aquifer, primarily TCE, DCE, and VC. TCE, a dense nonaqueous phase liquid (DNAPL), in the pure phase would be expected to be present near the bottom of the water column, whereas VC, a light nonaqueous phase liquid (LNAPL), in the pure phase would be expected to be present near the top of the water column. In the dissolved phase, both of these compounds move with ground-water flow. The depth intervals selected were near the top of the water column, in the screened interval, and near the bottom of the well. Samples were collected near the top of the water column for each well, but obstructions in some wells made collecting samples near the screened interval and the bottom impossible. Because the screened interval and bottom samples were difficult or impossible to collect, only two samples were collected per well, except for wells 2 and 5A. Obstructions in wells 1 and 3A were identified during a borehole video camera survey. In well 1, the filtration cone from the turbine pump was lodged in the casing at 840 ft. In well 3A, debris from a previous attempt to remove the turbine pump blocked the well at 1,175 ft. Wells 2A and 4A were sampled at depths greater than the maximum length of the video camera cable; however, obstructions were encountered by the downhole samplers at 1,875 and 1,950 ft, respectively. In well 5A, the video camera showed an obstruction in the well that appeared to be mud at 1,325 ft. The well intervals sampled for each of the production wells and the abandoned well are listed in table 4.

Water samples from wells 1, 2, 2A, 3A, 4A, and 5A were analyzed by E/A&H's contract laboratory, Compuchem Environmental Corp. Oil bailed from wells 2A, 3A, 4A, and 5A was sampled by E/A&H and analyzed by the contract laboratory, National Environmental Testing, Inc.

To collect samples from the desired depths, a downhole sampler with an electronically operated intake port was lowered into the well by a winch with a depth counter to a specified depth. Then the port was opened and the sample was collected. The port was closed for the return trip, and the sample was transferred to a container at the surface. A small downhole sampler, capable of collecting about 1 L (liter) of water per trip, was used to collect samples for analysis of VOCs and physical and chemical properties (pH, temperature, conductivity, and alkalinity). The sampler used a stopcock with a Teflon tube at the bottom of the barrel for transfer of water to sample containers, thus minimizing exposure of the samples to the atmosphere. After VOC samples were collected, the electronic component was unscrewed from the top of the barrel, and the remaining water was analyzed in the field for physical and chemical properties.

A larger downhole sample barrel was used to collect samples for SVOC, PCB, pesticide, cyanide, trace element, and major ion analyses. The large downhole sample barrel was capable of holding approximately 3 L

Table 3. Constituents analyzed by contract laboratory and associated reporting limits

[Anions: sulfate, nitrate, chloride, and alkalinity (CRQL is 10 µg/L); cyanide (CRQL is 10 µg/L); and total petroleum hydrocarbons (no CRQL) were analyzed by the contract laboratory, Compuchem Environmental Corp. Oil samples were analyzed by the contract laboratory, National Environmental Testing. Temperature, conductivity, pH, and alkalinity were measured in the field. CRQL, contract required quantitation limit (Robert Meierer, Compuchem Environmental Corp., written commun., 1995); µg/L, micrograms per liter, PCB, polychlorinated byphenyl]

Volatile organic compounds	CRQL (µg/L)	Semivolatile organic compounds	CRQL (µg/L)	Pesticides and PCB aroclors	CRQL (µg/L)	Trace elements and major ions	CRQL (µg/L)
1,1,1-Trichloroethane	1	1,2,4-Trichlorobenzene	10	4,4' -DDD	0.1	Aluminum	20
1,1,2,2-Tetrachloroethane	1	1,2-Dichlorobenzene	10	4,4' -DDE	.1	Antimony	60
1,1,2-Trichloroethane	1	1,3-Dichlorobenzene	10	4,4' -DDT	.1	Arsenic	10
1,1-Dichloroethane	1	1,4-Dichlorobenzene	10	Aldrin	.05	Barium	200
1,1-Dichloroethylene	1	2,4,5-Trichlorophenol	25	Dieldrin	.1	Beryllium	5
1,2-Dichloroethane	1	2,4,6-Trichlorophenol	10	alpha-Chlordane	.05	Cadmium	5
cis-1,2-Dichloroethylene	1	2,4-Dichlorophenol	10	gamma-Chlordane	.05	Calcium	5,000
trans-1,2-Dichloroethylene	1	2,4-Dimethylphenol	10	Endosulfan I	.05	Chromium	10
1,2-Dichloropropane	1	2,4-Dinitrophenol	25	Endosulfan II	.1	Cobalt	50
1,2-Dibromoethane	1	2,4-Dinitrotoluene	10	Endosulfan sulfate	.1	Copper	25
1,2-Dichlorobenzene	1	2,6-Dinitrotoluene	10	Endrin	.1	Iron	100
1,3-Dichlorobenzene	1	2-Methylnaphthalene	10	Endrin aldehyde	.1	Lead	3
1,4-Dichlorobenzene	1	2-Chloronaphthalene	10	Endrin ketone	.1	Magnesium	5,000
1,2-Dibromo-3-chloropropane	1	2-Chlorophenol	10	Heptachlor	.05	Manganese	15
2-Butanone	5	2-Methylphenol	10	Heptachlor epoxide	.05	Mercury	2
2-Hexanone	5	2-Nitroaniline	25	Methoxychlor	.5	Nickel	40
4-Methyl-2-pentanone	5	2-Nitrophenol	10	Toxaphene	5	Potassium	5,000
Acetone	5	3,3'-Dichlorobenzidine	10	alpha-BHC	.05	Selenium	5
Benzene	1	3-Nitroaniline	25	beta-BHC	.05	Silver	10
Bromochloromethane	1	4,6-Dinitro-2-methylphenol	25	delta-BHC	.05	Sodium	5,000
Bromodichloromethane	1	4-Bromophenyl-phenylether	10	gamma-BHC	.05	Thallium	10
Bromoform	1	4-Chloro-3-methylphenol	10	Aroclor-1016	1.0	Vanadium	50
Bromomethane	1	4-Chloroaniline	10	Aroclor-1221	2.0	Zinc	20
Carbon disulfide	1	4-Chlorophenyl-phenylether	10	Aroclor-1232	1.0		
Carbon tetrachloride	1	4-Methylphenol	10	Aroclor-1242	1.0		
Chlorobenzene	1	4-Nitroaniline	10	Aroclor-1248	1.0		
Chloroethane	1	4-Nitrophenol	25	Aroclor-1254	1.0		
Chloroform	1	Acenaphthene	10	Aroclor-1260	1.0		
Chloromethane	1	Acenaphthylene	10				
Dibromochloromethane	1	Anthracene	10				
Ethylbenzene	1	Benzo(a)anthracene	10				
Methylene chloride	2	Benzo(a)pyrene	10				
Styrene	1	Benzo(b)fluoranthene	10				
Tetrachloroethene	1	Benzo(g,h,i)perylene	10				
Toluene	1	Benzo(k)fluoranthene	10				
Trichloroethylene	1	Butylbenzylphthalate	10				
Vinyl chloride	1	Carbazole	10				
Xylene (total)	1	Chrysene	10				
cis-1,3-Dichloropropene	1	Di-n-butylphthalate	3				
trans-1,3-Dichloropropene	1	Di-n-octylphthalate	10				
		Dibenz(a,h)anthracene	10				
		Dibenzofuran	10				
		Diethylphthalate	10				
		Dimethylphthalate	10				
		Fluoranthene	10				
		Fluorene	10				
		Hexachlorobenzene	10				
		Hexachlorobutadiene	10				
		Hexachlorocyclopentadiene	10				
		Hexachloroethane	10				
		Indeno(1,2,3-cd)pyrene	10				
		Isophorone	10				
		N-Nitroso-di-n-propylamine	10				
		N-Nitrosodiphenylamine	10				
		Naphthalene	10				
		Nitrobenzene	10				
		Pentachlorophenol	25				
		Phenanthrene	10				
		Phenol	10				
		Pyrene	10				
		bis(2-Chloroethoxy)methane	10				
		bis(2-Ethylhexyl)phthalate	10				
		bis(2-chloroethyl)ether	10				
		bis(2-chloroisopropyl)ether	10				

Table 4. Water-quality sampling data from production and abandoned wells at the Naval Weapons Industrial Reserve Plant, Dallas, Texas

[Depth is in feet below land surface. ~, approximate]

Well and sample interval number	Date	Depth to water (feet)	Sample collection depth (feet)	Depth above top of screen (feet)	Comments
1–01	4–12–95	450	453		Top of water column
1–02	4–12–95		840	134	Obstruction encountered
2–01	4–18–95	37	~38		Electronic sampler unavailable; used a bailer (abandoned well)
2A–01	4–15–95	630	850		Sampled at this depth to avoid oil in water column
2A–02	4–15–95		1,875	90	Obstruction encountered
3A–01	4–16–95	650	660 and 675		Oil at 660; all samples, except total petroleum hydrocarbons, collected at 675
3A–02	4–16–95		1,175	865	Obstruction encountered
4A–01	4–14–95	640	646		Top of water column
4A–02	4–15–95		1,950	115	Obstruction encountered
5A–01	4–13–95	635	639	63	Top of water column
5A–02	4–13–95		1,150		
5A–03	4–13–95		1,325	Unknown	Obstruction encountered

of water. The large sample barrel was equipped with an electronically operated intake port. Two trips downhole for each interval sampled were required to collect sufficient water to fill the sample containers. At the surface, the electronic component was unscrewed from the top of the barrel, and the water was transferred to sample containers. The sample for well 2 was collected with a clean 2-ft long Teflon bailer supplied by E/A&H.

A duplicate sample was collected from well 2A (sample 2A–02D) for quality control. Field blanks for VOCs and SVOCs were collected for all wells except 2 and 5A. Trip blanks were included in all shipping containers of VOC samples. Lab blanks and blank spikes were run by the laboratory. Samples were kept on ice or refrigerated and shipped on ice.

E/A&H sampled well 1 for VOCs in January 1994. The sample was collected after the well was pumped and is considered representative of Paluxy aquifer water.

Borehole Geophysical Logging

Borehole geophysical logging entails recording and analyzing measurements of geophysical properties in boreholes. Geophysical data (logs) are collected by downhole logging tools along a continuous profile of the borehole. Logging tools "sample" a volume surrounding the nominal measurement depth that typically is about 1 ft in radius. Selected geophysical logs were run in the five production wells and three abandoned wells (table 5). Resistivity logs run prior to the study in the boreholes of wells 2A, 3A, and 4A and micrologs run in the boreholes of wells 2A and 4A were provided by the NWIRP contract operator. The following paragraphs give a brief discussion of each of the logs used.

Electrical-resistivity logging tools measure the electrical resistance of the formation. Electrical resistivity logs cannot be run in a cased borehole because the tool will not function in boreholes with electrically conductive steel casing. Low resistivity indicates electrically conductive clays and shales. High resistivity indicates massive carbonate rocks or sandstone aquifers saturated with freshwater. For this reason, the open-hole resistivity log is expected to be inversely correlated with the gamma and neutron logs. These three logs are useful as independent indicators of the lithologic response of logs. Anomalies on the gamma or neutron logs obtained

Table 5. Geophysical logs used at the Naval Weapons Industrial Reserve Plant, Dallas, Texas

[--, log not used]

Production wells

Well number	Resistivity	Micro-log	Natural gamma	Neutron	Density	Temperature	Caliper	Acoustic signature	Video
1	--	--	X	X	X	X	X	X	X
2A	X[1]	X[1]	X	X	X	X	X	X	X
3A	X[1]	--	X	X	X	X	X	X	X
4A	X[1]	X[1]	X	X	X	X	X	X	X
5A	--	--	X	X	X	X	X	X	X

Abandoned wells

Well number	Resistivity	Micro-log	Natural gamma	Neutron	Density	Temperature	Caliper	Cement bond	Video
2	--	--	X	X	--	--	--	X	X
3	--	--	X	X	X	--	X	X	X
4	--	--	X	X	X	--	--	X	X

[1] Logs run by Schlumberger.

within the cased boreholes often correlate with the open-borehole resistivity logs run prior to casing installation. This correlation demonstrates that the anomalies can be attributed to lithology and not voids behind casing.

Micrologs are detailed-scale electrical-resistivity logs. They can provide information on relative permeability by indicating effective porosity (a measure of the amount of interconnected pore space available for fluid flow and thus an index of permeability). A sensor, which is mounted on a pad pressed against the borehole wall, measures the formation resistivity at shallow depths. Differences between formation resistivity measured with deeper viewing probes and that measured by the microlog are used as an indication of permeability of the formation. The differences in resistivity are attributed to invasion of the formation by drilling fluid. The microlog senses resistance in permeable intervals because (1) resistive mud cake builds up on the borehole wall, and (2) relatively fresh drilling fluid displaces more saline formation water from the pore spaces adjacent to the well. The amount of invasion often is related to the effective porosity of the formation in physical models of invasion.

The natural gamma log records the rate of gamma emission from naturally radioactive minerals in the formation adjacent to the borehole. These minerals contain gamma emitting isotopes of uranium, potassium, and thorium and daughter products such as radium produced by the decay of those isotopes. In sedimentary formations, natural gamma activity is assumed to be linearly related to the clay mineral fraction in the formation (Keys, 1986). For this reason, the gamma log is considered to indicate lithology.

The neutron logging tool uses a neutron source to generate a neutron flux into the surrounding formation. The neutrons are scattered by collision with atoms in the casing and the formation. A detector located about 1 ft uphole from the source measures the rate at which neutrons are scattered back toward the borehole axis. The back-scattered flux of neutrons is affected strongly by the amount of hydrogen within the scattering volume. The neutron log, given in counts per second, is considered to be inversely proportional to the total water content of the formation, modulated by the neutron absorption cross section of the minerals within the formation. Therefore, the neutron log indicates both lithology and the amount of water-filled porosity. The neutron log also can show the presence of a void behind casing, where the water-filled void indicates an interval of anomalously large porosity.

The gamma-gamma or density log is analogous to the neutron log, except that the logging tool uses a gamma source, and the attenuation of back-scattered gamma radiation is attributed to the mass density of the formation. The gamma-gamma logging tool uses two detectors at different distances above the source. The tool is decentralized (pressed against the borehole wall) by a caliper arm during logging, and the borehole side of the logging tool is shielded by gamma-absorbing material. This tool design allows the correction of tool response to eliminate the effects of borehole diameter and the effects of gaps between the logging tool and the borehole (Scott, 1977; Hearst and Nelson, 1985). The conventional calibration of the gamma-gamma log could not be applied in this study because the logs were run in a cased borehole with unknown conditions within the annulus between the casing and formation. However, the gamma-gamma log response does indicate the average density of the material between casing and formation. A void (anomalously low density) in the annulus would be associated with large counting rates in either or both detectors (long- and short-spaced).

Temperature logs can indicate when water is moving along open boreholes or behind casing (Keys, 1990; Paillet, 1993). If there is no flow in a borehole, the temperature log shows a linear increase in temperature with depth. Slight changes in the temperature gradient often are associated with lithologic contacts. However, larger changes in measured temperature gradients can indicate that fluid is moving along the borehole. Very large temperature gradients often indicate the specific places where water enters or exits from the borehole.

The single-arm caliper is run in association with the gamma-gamma (density) log to ensure the decentralization of the tool (Scott, 1977). The single-arm caliper log can be used to identify departures from the expected uniform inside diameter of casing in boreholes. A change in the diameter can indicate damage, which can affect the mechanical integrity of the casing.

The cement-bond log is a specialized application of the acoustic signature log (Hearst and Nelson, 1985; Paillet and Cheng, 1991). The acoustic signature log is run by recording the pressure signals received a short distance uphole from an ultrasonic energy source operating at a frequency of about 10 khz (kilohertz). The logging tool is centralized in the middle of the casing by bowsprings or other mechanical arms so as to give full azimuthal coverage; the readings around the circumference then are averaged. The acoustic signature log is interpreted in cased boreholes by assuming that the recorded acoustic waves indicate the acoustic properties of the formation if casing is tightly bound to the formation by cement. If there is a void between the casing and the formation, the measured acoustic signature indicates the steady resonant vibration of the "free pipe" (Gai and Lockyear, 1992; Bigelow, 1993). Interpretation of the free pipe condition is based on (1) recognizing an anomalously high amplitude in the first acoustic arrivals, and (2) recognizing a uniformity of signal with depth that does not contain natural variations expected to indicate natural variations in the acoustic properties of formations around the well bore.

The borehole video provides images with accurate location of screens, perforations, couplings, and damaged casing (Keys, 1990). These images are useful for visually inspecting and recording the internal conditions of the well casing and for determining well conditions before more expensive nuclear logging tools are lowered into the borehole. Visual inspection can be difficult if the water in the well is not clear.

Except for the cement-bond log, all of the logs for this study were run with the logging probe decentralized (probe pressed against the side of the borehole by a caliper arm) or in the "free-hanging" mode, where the tool is aligned along the "downhill" side of the casing. In this free-hanging mode, the logging-tool response is affected by the large borehole diameter because only about one-half of the sampled volume consists of formation, casing, and annulus; the other one-half of the sampled volume is filled with water or air. The use of such logging tools, which are designed for relatively small-diameter boreholes, complicates the interpretation of these logs but by no means precludes their use to interpret the conditions behind casing.

INTEGRITY OF PRODUCTION WELLS

Integrity of the production wells was determined using water-quality and borehole geophysical data. The chemical character of the water column in each production well was analyzed to determine presence or absence of target compounds detected in the shallow alluvial aquifer. The soundness of the casings and cement around the casings was assessed using borehole geophysical logs.

Water-Quality Data

The following sections discuss the results of laboratory analysis of selected groups of constituents sampled from wells at the NWIRP. The results were used to determine whether contaminants in the shallow alluvial aquifer were also present in the water column of the production wells. The regulatory action level for this site is the practical quantification limit (PQL) (U.S. Environmental Protection Agency, 1993). PQLs for selected constituents are listed in table 6. Complete laboratory results from this study are available upon request.

Table 6. Selected results of laboratory analysis of volatile organic compounds, semivolatile organic compounds, pesticides, polychlorinated biphenyls, and total petroleum hydrocarbons in ground-water samples from the Naval Weapons Industrial Reserve Plant, Dallas, Texas

[Polychlorinated biphenyls (PCBs) were not detected in any sample. µg/L, micrograms per liter; PQL, practical quantitation limit (U.S. Environmental Protection Agency, 1993); PCB, polychlorinated biphenyl; mg/L, milligrams per liter; ND, nondetect; --, no data]

Well and sample interval no.	Volatile organic compounds			Semivolatile organic compounds			Pesticides and PCBs			Total petroleum hydrocarbons (mg/L)
	Name	Concentration (µg/L)	PQL (µg/L)	Name	Concentration (µg/L)	PQL (µg/L)	Name	Concentration (µg/L)	PQL (µg/L)	
1–01	ND	--	--	ND	--	--	Methoxychlor	[1,2]0.01	2	[1]0.15
							Endrin aldehyde	[1,2].01	.2	
							Endosulfan I	[1].001	.1	
1–02	Methylene chloride	[3]4	5	bis(2-Ethylhexyl)phthalate	[1]1	20	ND	--	--	ND
2–01	Methylene chloride	[3]2	5	Not sampled	--	--	Not sampled	--	--	Not sampled
	Acetone	10	100							
	Benzene	1	2							
2A–01	Toluene	[1]1	2	4-Methylphenol	[1]22	10	Heptachlor	[1,2].01	.05	8.3
							Endosulfan I	[1,2].002	.1	
							Methoxychlor	[1].23	2	
							Endrin ketone	[1,2].01	.01	
2A–02	Methylene chloride	[1].5	5	bis(2-Ethylhexyl)phthalate	[1]2	20	Methoxychlor	[1,2].09	2	4.7
							Endrin ketone	[1,2].004	.01	
3A–01	Methylene chloride	[1].8	5	ND	--	--	Methoxychlor	[1,2].23	2	20,000
3A–02	Methylene chloride	[1].6	5	ND	--	--	Heptachlor	[1,2].002	.05	16
							Methoxychlor	[1,2].33	2	
4A–01	ND	--	--	N-Nitrosodiphenylamine	[1]4	10	Heptachlor	[1,2].001	.05	[1].99
							Aldrin	[1,2].002	.05	
							Dieldrin	[1,2].001	.1	
							4,4'-DDE	[1,2].001	.05	
							Methoxychlor	[1,2].003	2	
							Endrin ketone	[1,2].001	.01	
							Alpha-chlordane	[1,2].003	.1	
4A–02	Methylene chloride	[1,3].7	5	ND	--	--	ND	--	--	[1].23
5A–01	Methylene chloride	[3]3	5	ND	--	--	ND	--	--	20
5A–02	Methylene chloride	[1,3]1	5	ND	--	--	ND	--	--	8.1
5A–03	Methylene chloride	[3]2	5	ND	--	--	ND	--	--	14

[1] Estimated.

[2] Greater than 25-percent difference between concentrations from two gas chromatographs.

[3] Found in associated lab blank (table 7).

The deep production wells used turbine pumps to pump water from the aquifer to the surface. These pumps were lubricated regularly during their lifetime. Prior to sampling, an attempt was made to remove all of the oil from the wells, however, some wells had large amounts of oil that could not be completely removed with a bailer (Ted Blahnik, EnSafe/Allen & Hoshall, oral commun., 1995).

Volatile Organic Compounds

TCE and its degradation products are the primary organic contaminants of concern in the shallow alluvial aquifer at the NWIRP (Jeff James, EnSafe/Allen & Hoshall, oral commun., 1996). TCE concentrations in the shallow alluvial aquifer as mapped by E/A&H in August 1995 are shown in figure 3. The five deep production wells and one abandoned well (2) were sampled to determine if TCE, its degradation products, or other organic contaminants found in the shallow alluvial aquifer were present in the water column of these wells. TCE and its degradation products, DCE and VC, were not detected in any of the samples from the production wells (wells 1, 2A, 3A, 4A, and 5A) or the sample from the abandoned well (well 2). The results of sample analysis of organic compounds from the wells listed above are listed in table 6.

Methylene chloride was detected in nine ground-water samples and one field blank and was equal to or greater than the CRQL (2 µg/L (micrograms per liter); table 3) in samples 1–02, 2–01, 5A–01, and 5A–03, but all concentrations were less than the PQL (5 µg/L). Methylene chloride is a common laboratory contaminant, and the qualifier (table 6, footnote 3) assigned by the laboratory indicates that the compound also was detected in the associated lab blank (table 7) as well as the sample. A lab blank is run by the laboratory with blank water and is used to identify any interferences or contamination of the analytical system that might lead to the reporting of elevated analyte concentrations or false positive data. Acetone and benzene were detected in sample 2–01. Acetone, another common laboratory contaminant, was detected in the field blank from well 4A. Toluene was detected at concentrations less than the CRQL and PQL. The presence of toluene in sample 2A–01 could be due to the presence of oil on top of the water column or field contamination of the sample. Concentrations of all VOCs detected in ground-water samples were less than the PQL, which is the regulatory action level for this site.

The VOC concentrations in all the samples either are qualified as estimated because the concentrations detected were less than the CRQL (table 3) but greater than zero, or are qualified because the constituent reported also was detected in the associated lab blank (Robert Meierer, Compuchem Environmental Corp., written commun., 1995). The target compounds TCE, DCE, and VC were not detected in any of the samples.

Ground-water samples collected from the second and third depth intervals (table 4) degassed when brought to surface atmospheric pressures. This degassing caused air voids to form in the sample containers. The laboratory was notified of the air voids and instructed to choose the sample containers with the smallest air void for analysis. Loss of some volatile compounds could have occurred because of volatilization in the sample container. The most likely compounds to volatilize are chloromethane, chloroethane, VC, and bromomethane (Cathy Dover, Compuchem Environmental Corp., written commun., 1995). Of these compounds, only VC is a contaminant of concern in the shallow alluvial aquifer. VC is a LNAPL and would be expected to be present at the top of the water column (in its nonaqueous phase) where degassing of the samples did not occur.

E/A&H sampled well 1 for VOCs in January 1994. The sample was collected after the well was pumped and is considered a representative sample of water in the Paluxy aquifer. VOCs were not detected.

Semivolatile Organic Compounds

SVOCs were not detected above the CRQL (table 3) for any of the ground-water samples collected at the NWIRP, however, the sample from 2A–01 was diluted at a 10:1 ratio, which increased the CRQL for each constituent by a factor of 10. The only SVOC detected in sample 2A–01 was 4-Methylphenol. All SVOCs detected were less than the PQL (except 4-Methylphenol in sample 2A–01). 4-Methylphenol is used as a disinfectant, surfactant, synthetic food flavorer, and textile scouring agent, as well as for other uses (Montgomery and Welkom, 1990). Two SVOCs, bis(2-Ethylhexyl)phthalate, and N-nitrosodiphenylamine, were less than the CRQL of 10 µg/L (tables 3 and 6). Bis(2-Ethylhexyl)phthalate is a common laboratory contaminant and also was detected in one of the lab blanks (table 7). N-nitrosodiphenylamine is used as a rubber accelerator, solvent in fiber and plastics industries, rocket fuel, pesticide, lubricant, and for many

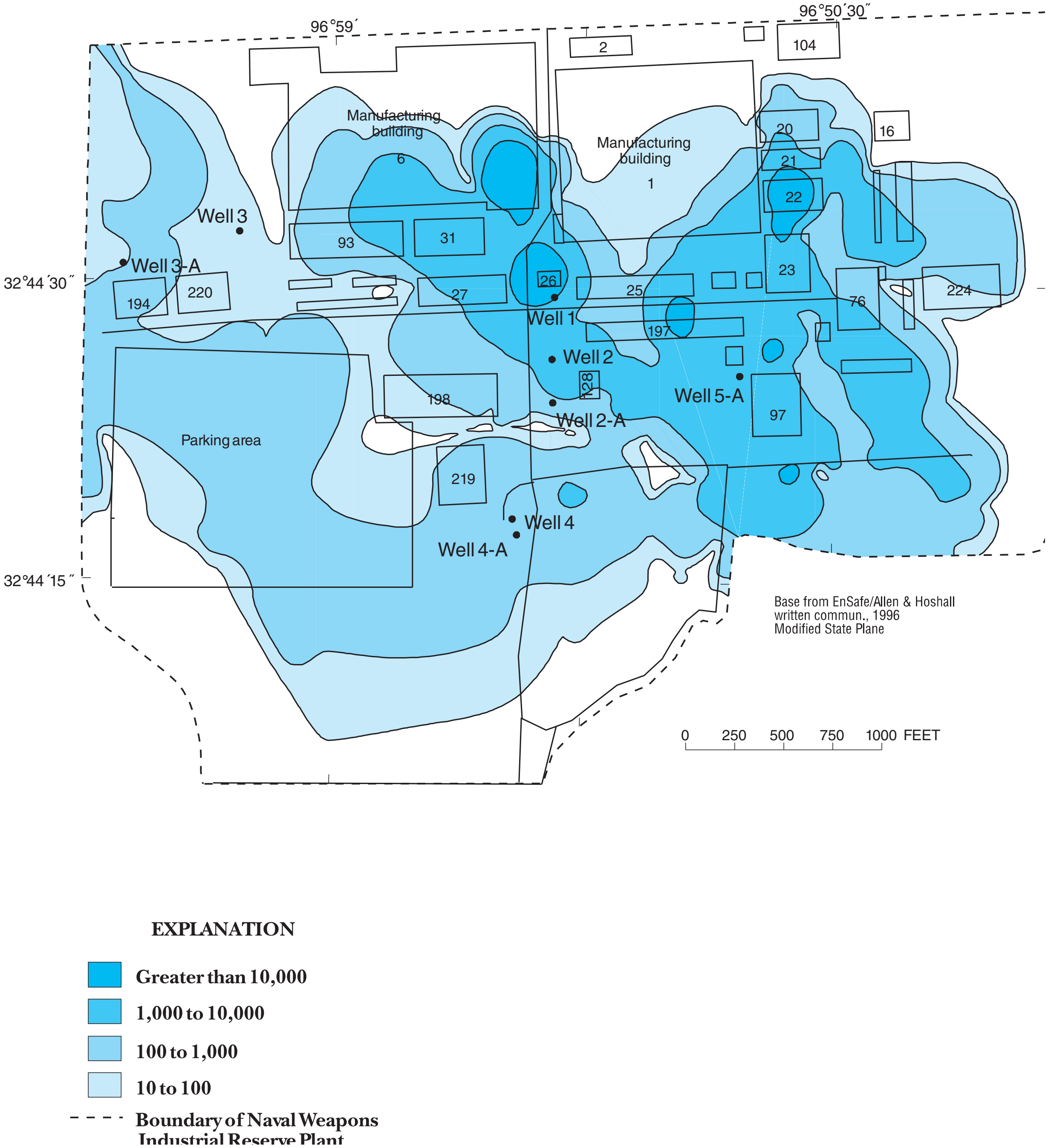

Figure 3. Trichloroethylene concentrations in the shallow alluvial aquifer at the Naval Weapons Industrial Reserve Plant, Dallas, Texas.

other uses (Montgomery and Welkom, 1990). The qualifier (table 6, footnote 1) used on all results indicates the concentrations are estimated because the detections were less than the CRQL but greater than zero. Many of the samples had tentatively identified compounds (tics). These tics were mostly unknown compounds, unknown hydrocarbons, and butylated hydroxytoluene. Butylated hydroxytoluene was considered a fairly good match based on comparison of known compounds in the SVOC library (Robert Meierer, Compuchem Environmental Corp., written commun., 1995). These tics were most likely related to the oil on top of the water column.

The sample 5A–01 was concentrated to a final extract volume of 5 mL (milliliters), and the sample

Table 7. Selected results of field and laboratory quality-control samples from the Naval Weapons Industrial Reserve Plant, Dallas, Texas

[Concentrations are in micrograms per liter except for sulfate and dissolved solids, which are in milligrams per liter. PCB, polychlorinated biphenyl; ND, nondetect; --, no data; NA, not applicable]

FIELD QUALITY-CONTROL SAMPLES

Quality control type and identifier	Volatile organic compounds	Concentration	Semivolatile organic compounds	Concentration	Pesticides and PCBs	Concentration	Trace elements, ions, and dissolved solids	Concentration
Replicate								
2A–02D	Methylene chloride	[1]0.6	bis(2-Ethylhexyl)phthalate	[1]2	ND	--	Chromium	22
							Copper	247
							Iron	56,000
							Lead	65
							Manganese	663
							Zinc	528
							Sulfate	3,350
							Dissolved solids	5,250
Trip blanks								
[2]1	Methylene chloride	[1]3	NA	--	NA	--	NA	--
[3]2	Methylene chloride	[1]1	NA	--	NA	--	NA	--
[4]3	Methylene chloride	[1].9	NA	--	NA	--	NA	--
Field blanks								
Well 1	Methylene chloride	[1]1	Di-n-butylphthalate	[1]3	NA	--	NA	--
Well 2A	ND	--	bis(2-Ethylhexyl)phthalate	[1]3	NA	--	NA	--
Well 3A	ND	--	bis(2-Ethylhexyl)phthalate	[1]1	NA	--	NA	--
Well 4A	Acetone	220	ND		NA	--	NA	--

LABORATORY QUALITY-CONTROL SAMPLES

Quality control type and identifier	Volatile organic compounds	Concentration	Semivolatile organic compounds	Concentration	Pesticides and PCBs	Concentration	Trace elements, ions, and dissolved solids	Concentration
Lab blanks								
[5]1	Methylene chloride	[1]1	[6]bis(2-Ethylhexyl)phthalate	[1]2	ND	--	NA	--
[7]2	Methylene chloride	[1].9	ND	--	ND	--	NA	--
[8]3	ND	--	ND	--	ND	--	NA	--

[1] Estimated.
[2] Trip blank 1 applies to samples 1–01, 1–02, 5A–01, 5A–02, and 5A–03.
[3] Trip blank 2 applies to samples 2A–01, 2A–02, 2A–02D, 3A–01, 3A–02, 4A–01, and 4A–02.
[4] Trip blank 3 applies to sample 2–01 only.
[5] Lab blank 1 applies to samples 1–02, 4A–01, 4A–02, 5A–01, 5A–02, and 5A–03.
[6] Lab blank applies to sample 4A–01 only.
[7] Lab blank 2 applies to samples 2A–01, 2A–02, 2A–02D, 3A–01, and 3A–02.
[8] Lab blank 3 applies to sample 1–01 only.

extract was diluted at a 10:1 ratio, creating an effective dilution of 50:1, which diluted out the surrogates. Other samples analyzed at lesser dilutions produced surrogate recoveries within acceptable limits (Robert Meierer, Compuchem Environmental Corp., written commun., 1995).

Pesticides and Polychlorinated Biphenyls

Pesticide and PCB concentrations were not detected above the CRQL in any of the ground-water samples collected at the NWIRP (tables 3 and 6). The pesticide endrin ketone detected in sample 2A–01 was equal to the PQL, but the concentration was considered an estimate. All reported pesticide results, except endosulfan I in sample 1–01 and methoxychlor in sample 2A–01, required two qualifiers (table 6). The qualifiers indicate the concentrations are estimated because the detections were less than the CRQL (table 6, footnote 1) but greater than zero, and that there was a greater than 25-percent difference for detected concentrations between the two gas chromatographic columns used to analyze the sample (table 6, footnote 2). The lower of the two concentrations detected by the gas chromatograph is the one reported by the laboratory.

Total Petroleum Hydrocarbons

TPH concentrations in water for each of the samples from the production wells are listed in table 6. The elevated TPH concentration in sample 3A–01 was caused by excess oil in the sample. Sample 3A–01 was collected in an area of the water column where an appreciable amount of oil remained in the well. Surrogate recoveries were within quality-control limits for all samples except 2A–01, 3A–01, and 3A–02. In each sample, the presence of target or nontarget compounds interfered with the surrogate and prevented accurate identification and quantification (Roy Sutton, Compuchem Environmental Corp., written commun., 1995).

Excess floating oil was bailed off the top of the water column from wells 2A, 3A, 4A, and 5A and placed in drums for each well. To determine if the oil bailed from the wells was the same oil used to lubricate the turbine pumps, oil samples from the drums were collected by E/A&H for laboratory analysis of diesel range organics (modified U.S. Environmental Protection Agency method 8015). A raw sample of the oil believed used to lubricate the turbine pumps also was analyzed. The chromatographic pattern from the lubricating oil is similar to the chromatographic pattern from the oil present in the samples from the drums, which indicates that the oil present in the wells is probably from the lubrication of the turbine pumps.

Trace Elements and Major Ions

Results of field measurements and laboratory analyses for concentrations of field properties, major ions, dissolved solids, and total trace elements are listed in table 8. Many of the reported concentrations are qualified as estimated values. Most trace element concentrations were greater than the CRQL (table 3). Elevated concentrations could be a result of the geology of the area, residence time of the water in the casing, or leaching of the metal casings, screens, and turbine pumps. The composition of the steel used for well screens includes, but is not limited to, iron, nickel, chromium, manganese, copper, and zinc. Corrosion of metals in an aqueous environment has been well documented. When dissolved solids concentrations in water exceed 1,000 mg/L (milligrams per liter), electrolytic corrosion is likely to occur (Universal Oil Products Co., 1966); concentrations exceeded 1,000 mg/L in wells 2, 2A, 3A, 4A, and 5A.

Trace element and major ion concentrations in sample 2A–02 (table 8) and the accompanying duplicate 2A–02D (table 7) for that sample are much higher than concentrations in other samples. The reason for this chemical stratification is unknown; however, the pH measured in this sample was lower than in other samples, and the sulfate concentration was higher. Lower pH and elevated sulfate concentrations are often associated with corrosive attacks on metals (Universal Oil Products Co., 1966).

Chromium is the primary metal contaminant of concern at the site, but lead also has been detected in ground-water samples collected from the shallow alluvial aquifer. Chromium concentrations in the production-well samples were not greater than the PQL (70 µg/L) in any well, but lead was above the PQL (40 µg/L) in samples 1–01 and 2A–02 (fig. 4) (U.S. Environmental Protection Agency, 1993). The highest chromium concentration was detected in sample 2A–02 at 62 µg/L. Samples 1–01 and 2A–02 had lead concentrations of 61 and 110 µg/L, respectively. The duplicate analyses for chromium and lead yielded concentrations of 22 µg/L and 65 µg/L, respectively (table 7). All wells are located in the chromium plume area (concentrations less than 300 µg/L) of the shallow alluvial aquifer as mapped by E/A&H (written commun., 1995). Wells 3,

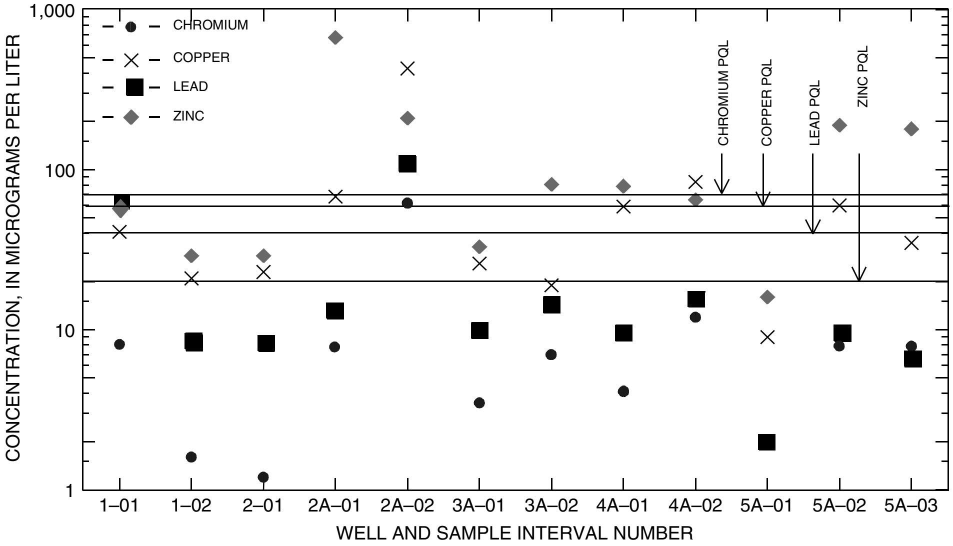

Figure 4. Concentrations of chromium, copper, lead, and zinc and the corresponding practical quantitation limit (PQL) at each sampling depth in the wells at the Naval Weapons Industrial Reserve Plant, Dallas, Texas. (See table 7; some concentration data are qualified as estimates for chromium, copper, lead, and zinc.)

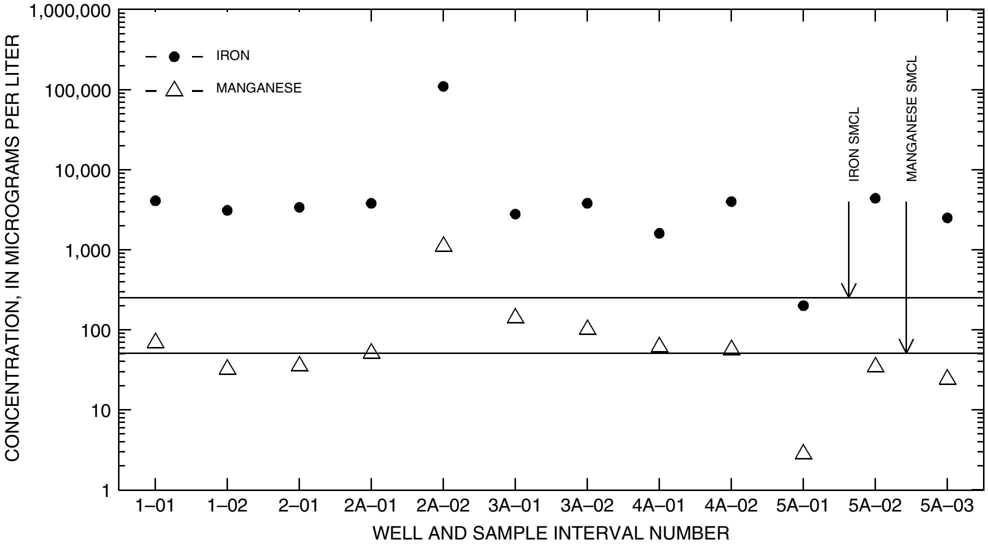

Figure 5. Concentrations of iron and manganese and the corresponding secondary maximum contaminant level (SCML) at each sampling depth in the wells at the Naval Weapons Industrial Reserve Plant, Dallas, Texas.

3A, 4, and 4A are in areas where plume concentrations of chromium are less than 20 µg/L.

Other trace elements that had concentrations greater than the PQL were copper and zinc (fig. 4). Copper concentrations were at or greater than the PQL (60 µg/L) for samples collected from wells 2A–01, 2A–02, 4A–02, and 5A–02. Zinc concentrations were greater than the PQL (20 µg/L) for all wells and sampling depths except well 5A–01 (U.S. Environmental Protection Agency, 1993). Trace element concentrations and the PQL, where available for selected elements, are listed in table 8.

Iron and manganese do not have a PQL, but the secondary maximum contaminant levels (SMCL) are 0.3 mg/L (300 µg/L) and 0.05 mg/L (50 µg/L), respectively (U.S. Environmental Protection Agency, 1996). Iron was greater than the SMCL in all samples except 5A–01. Manganese was above the SMCL in samples from wells 1, 2A, 3A, and 4A (fig. 5).

Alkalinity (as calcium carbonate) concentrations were higher than sulfate and chloride concentrations in

Table 8. Selected field properties, major ions, dissolved solids, and total trace element concentrations in ground-water samples from the Naval Weapons Industrial Reserve Plant, Dallas, Texas

[Alkalinity was measured at the site for one sample per well; cyanide was not detected in any sample; practical quantification limit for chromium is 70 µg/L; copper 60 µg/L; lead 40 µg/L; zinc 20 µg/L. µS/cm, microsiemens per centimeter at 25 degrees Celsius; °C, degrees Celsius; $CaCO_3$, calcium carbonate; mg/L, milligrams per liter; µg/L, micrograms per liter; --, no data; ND, nondetect]

Well and sample interval no.	Field measurements				Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Sulfate (mg/L)	Chloride (mg/L)	Dissolved solids (mg/L)	Chromium (µg/L)	Copper (µg/L)	Iron (µg/L)	Lead (µg/L)	Manganese (µg/L)	Mercury (µg/L)	Zinc (µg/L)
	Specific conductance (µS/cm)	pH (standard units)	Temperature (°C)$^{\times}$	Alkalinity as $CaCO_3$ (mg/L)														
1–01	1,000	8.3	22.4	--	[1]4.1	[1]0.3	201	2.4	85	20	649	[1]8.1	41	4,100	61	69	ND	59
1–02	1,150	8.8	26.3	420	[1]1.2	[1].2	465	5.5	110	21	714	[1]1.6	[1]21	3,100	8.5	32	ND	29
2–01	--	--	--	--	[1]1.3	[1].2	492	6.0	550	140	1,610	[1]1.2	[1]23	3,400	8.5	35	ND	29
2A–01	--	9.2	26.5	--	[1].7	[1].2	427	11	680	78	2,210	[1]7.8	68	3,800	13	51	ND	670
2A–02	--	7.6	26.2	212	190	68	1,160	[1]12	3,200	32	5,220	62	430	110,000	110	1,100	ND	210
3A–01	--	9.0	25.2	--	[1]1.1	[1].1	441	44	540	74	1,390	[1]3.5	26	2,800	10	140	ND	33
3A–02	--	8.9	25.4	586	[1]1.1	[1].1	441	38	390	77	1,450	[1]7.0	[1]19	3,800	14	100	ND	81
4A–01	976	9.1	25.7	--	[1].9	[1].1	188	11	66	27	466	[1]4.1	59	1,600	9.5	61	ND	79
4A–02	1,670	8.8	25.2	520	[1]4.0	[1]1.1	322	6.6	260	72	1,040	12	84	4,000	15	56	ND	65
5A–01	1,460	9.1	23.8	--	[1].7	[1].1	48.4	[1].4	95	79	1,990	ND	[1]9.0	200	[1]2	2.8	ND	[1]16
5A–02	1,470	9.2	27.2	472	[1]2.0	[1].4	289	[1]2.0	99	75	860	[1]7.9	60	4,400	9.1	34	0.26	190
5A–03	1,480	8.1	27.5	--	[1]2.3	[1].5	288	[1]3.1	110	75	858	7.9	35	2,500	6.8	24	ND	180

[1] Estimated.

most samples. Sulfate concentration was very high in sample 2A–02 and the accompanying duplicate, 2A–02D (tables 7 and 8). Sample 2A–02 had a dissolved solids concentration of 5,220 mg/L, more than 10 times the lowest dissolved solids concentration (466 mg/L, sample 4A–01). In each well, except well 5A, the dissolved solids concentrations increase with depth. Samples from wells 1, 2A, 3A, 4A, and 5A were analyzed for cyanide, which was not detected in any of the samples.

Water-Level Data

The water level at well 2 (abandoned well) was measured at 37 ft below land surface. A comparison between the shallow alluvial aquifer water levels in that area and the water level in well 2 was made to determine if ground water from the shallow alluvial aquifer was moving into well 2. Water levels in wells completed in the shallow alluvial aquifer near well 2 are about 18 ft below land surface (Ted Blahnik, EnSafe/Allen & Hoshall, written commun., 1995). Because of the difference in water levels, it is unlikely that the standing water in well 2 is leakage from the shallow alluvial aquifer.

In April 1995, well 3 had about 17 ft of standing water in the casing and well 4 was completely dry. In order to run the acoustic signature log in the shallow wells, the wells were filled with water. In October 1995, wells 3 and 4 were still full of water, which indicates that ground-water movement from the formation into or out of the wells did not occur. Well 2 was unavailable for water-level measurement in October 1995 because a permanent structure had been built on top of the well.

Borehole Geophysical Data

To begin the analysis for this project, the logs were reviewed and methods by which the logs could be interpreted were identified. Log interpretation for the purpose of determining well integrity was approached by considering how the effect of possible voids and channels behind casing might be separated from the effect of lithology on the geophysical logs. This approach is possible because open-borehole logs for three of the five production wells are available. These logs provide direct information about the effects of formation lithology on log response. This known log response can be compared to the response in the corresponding cased-hole logs to identify variations or anomalies that might be related to poorly bonded intervals of casing. Composites of the open-hole logs (resistivity), the cased-hole logs (temperature, caliper, neutron, gamma, and density), and the cement-bond log were constructed to indicate possible problem areas in casing or cement of the five production wells. The patterns of variation were compared to open-hole logs and the stratigraphic column to determine whether the patterns of variation reflect lithology or whether they are associated with conditions within the annulus between casing and formation. The logs for the abandoned wells (2, 3, 4) were reviewed but are not discussed in the text. A complete set of geophysical logs for this study are available upon request.

The resistivity logs plotted in this report and correlated with the cased-hole logs are the long normal resistivity logs (wells 2A, 3A, and 4A). Small depth shifts were made in correlating these open-hole resistivity logs with cased-hole logs to provide maximum correlation between geologic units, a common practice in geophysical log analysis (Keys, 1990; Paillet and Crowder, 1996).

In this report, the acoustic signature logs were interpreted to generate a qualitative cement-bond log. This was done by assigning a cement-bond quality score ranging from 0 (completely free pipe) to 100 (fully bonded pipe). Examples of the acoustic signature logs associated with three different bonding scores are shown in figure 6. This qualitative assessment also was checked against the relative acoustic signature amplitude trace provided as part of the acoustic signature log format. However, the bond quality score also needs to be compared with natural variations in formation properties indicated by the other logs. Acoustic signature logs are affected by a number of formation properties. The association of a low bonding score with openings behind casing is more reliable when there is no correlation between the bonding score and the lithology indicated by other logs. The explanation of letters denoting features in figures 7–12 are listed in table 9.

All logs show the expected response to water level in the cased borehole (C on figs. 7–11) and to reductions in casing size (D on figs. 7, 8, 10, and 11) (table 9). The standing water in the casing attenuates gammas from the formation and neutrons from the neutron source in the neutron logging tools, so the gamma and neutron logs show abrupt decreases in count rates below the water level in casing. The long and short detector count rates on the density log show much smaller decreases because the shielding on the borehole side of the logging tool greatly decreases sensitivity to the properties of borehole fluid. The two density detec-

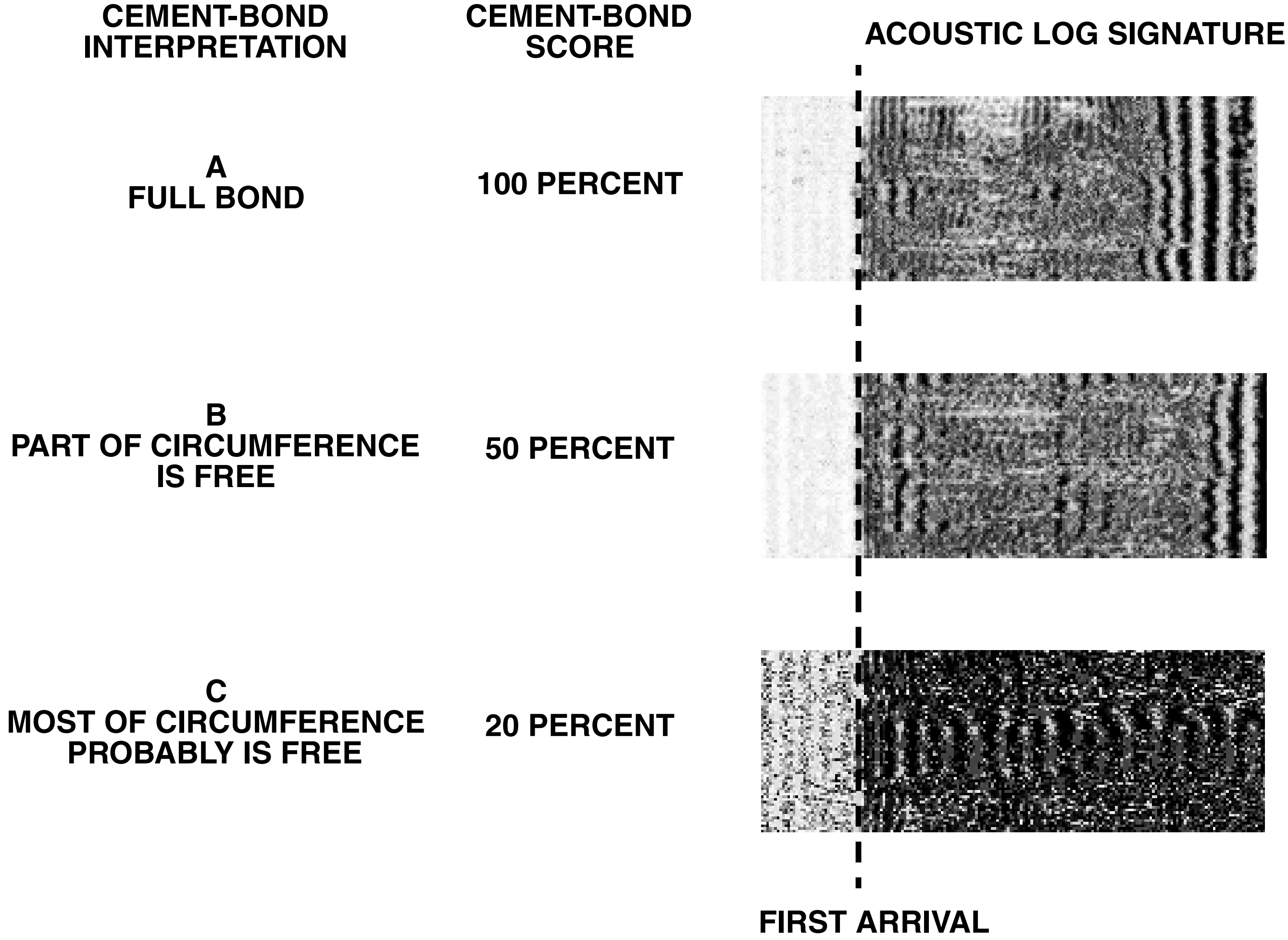

Figure 6. Diagram showing sample cement bonding scores obtained from the acoustic signature log.

tor counts show very sharp spikes associated with abrupt casing diameter changes. These spikes are caused by the effects of the passage of the density tool past the constriction in the casing.

The open-hole resistivity logs correlate closely with the cased-hole gamma log for the three boreholes where these logs are available (wells 2A, 3A, and 4A). Areas where gamma lows (indicative of massive limestone or clean sands) and highs (indicative of shale) correlate with resistivity lows are noted on the log composites (A, above water level and B, below water level). Variations related to lithology on the gamma and neutron logs are not very large, a characteristic that is expected because the response to lithology is suppressed by the effects of casing, cement, and the large volume of borehole fluid.

Neutron and gamma logs show good correlation with the electrical-resistivity logs. Variations in gamma logs in particular can be attributed to variation in lithology adjacent to the borehole because gamma logs are relatively insensitive to voids behind casing. The gamma logs can be used to show where anomalies in cement-bond or density logs can be attributed to variation in lithology behind casing, and where they can be attributed to possible voids behind casing. This joint interpretation of gamma, cement-bond, and density logs makes the interpretation more reliable than would be possible using cement-bond and density logs alone.

The secondary geophysical indicator of water- or air-filled channels behind casing was expected to be the density log because of the large contrast in density between saturated formation and water- or air-filled voids. The density log also was expected to be more

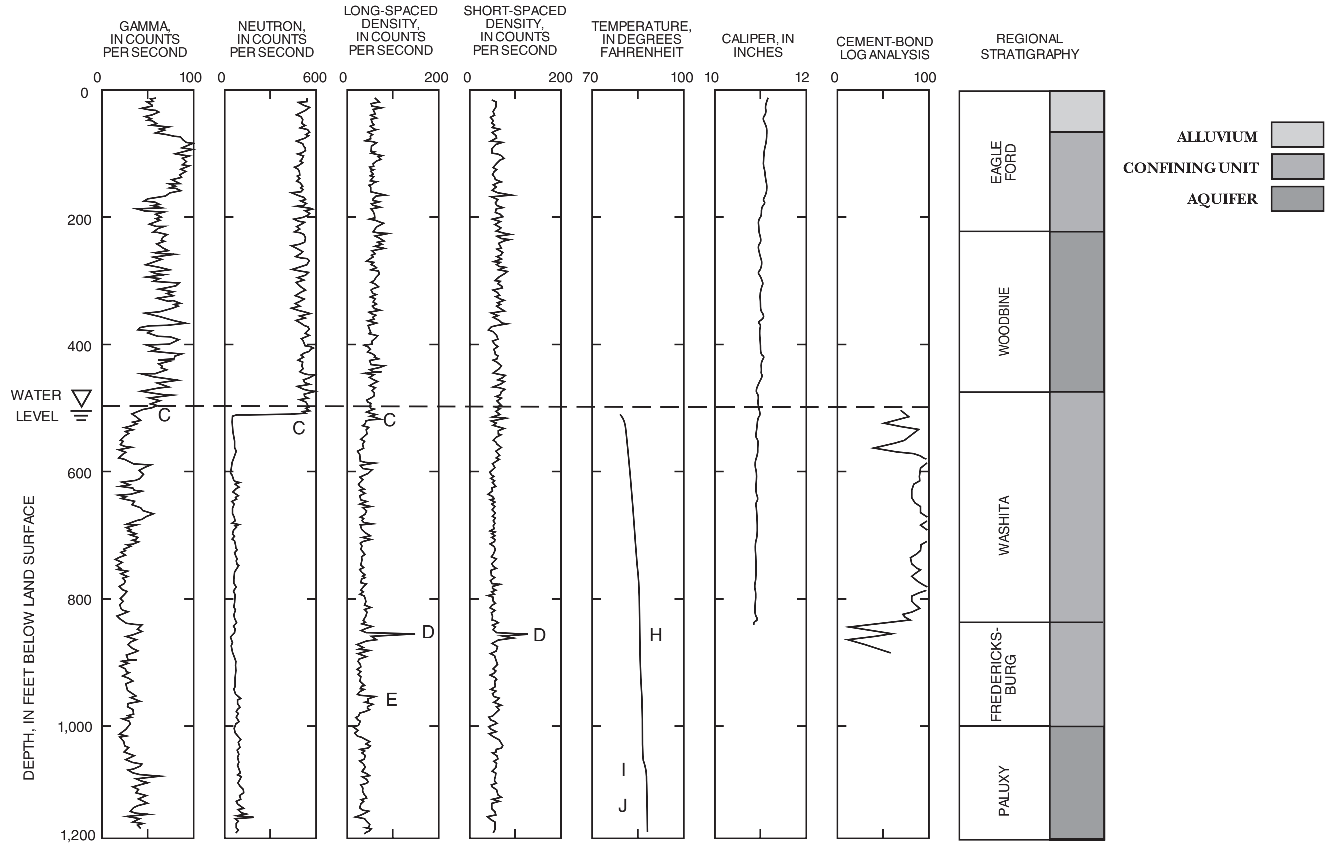

Figure 7. Log composite for well 1.

sensitive to voids behind casing because the compensated density probe is relatively insensitive to the fluid-filled borehole. The sensitivity of the density log is demonstrated by the response of the log to the presence of casing collars at 40-ft intervals (K on fig. 12 in a larger scale version of part of the log composite for well 2A). The dense steel of the collars produces a sharp deflection toward low count rates, which is especially apparent at the scale used to plot the logs in figure 12. The casing collar anomalies show up more clearly on the long-spaced density logs. This casing collar response indicates that the logs can detect features that are a function of borehole completion conditions. Large channels in the annulus would likely be a function of borehole completion as are the casing collars, so the data indicate that such channels would show up as anomalies on the long-spaced density log. For the most part, the long-spaced density log shows a weak correlation with lithology. In a few locations, local zones of anomalously high density count rates might indicate anomalously low density or voids behind casing (E in figs. 7, 8, 10, 11, and 12). A few of these possible voids also are correlated with neutron log deflections to slightly lower count rates, indicative of anomalously high water content (F in figs. 8, 10, 11, and 12). However, neutron-log anomalies would not be associated with possible air-filled voids behind casing because the back-scattered neutrons are attenuated only when such spaces are filled with water. Some of these anomalies correlate with possible intervals of poor bonding interpreted from analysis of the acoustic signature log.

Temperature logs (figs. 7–12) do not show anomalies large enough to indicate fluid flow behind casing, except in well 1 from about 1,080 ft to the bottom of the borehole. The temperature log shows an abrupt shift at the top of this interval and an isothermal character to the bottom of the borehole. This pattern is indicative of flow (Paillet, 1993), which in well 1 is consistent with the location of the screened interval. A few other points on the temperature log (H on figs. 7, 8, 9, and 11) show subtle changes in temperature gradient that might be related to weak flow in the annulus; but they also could

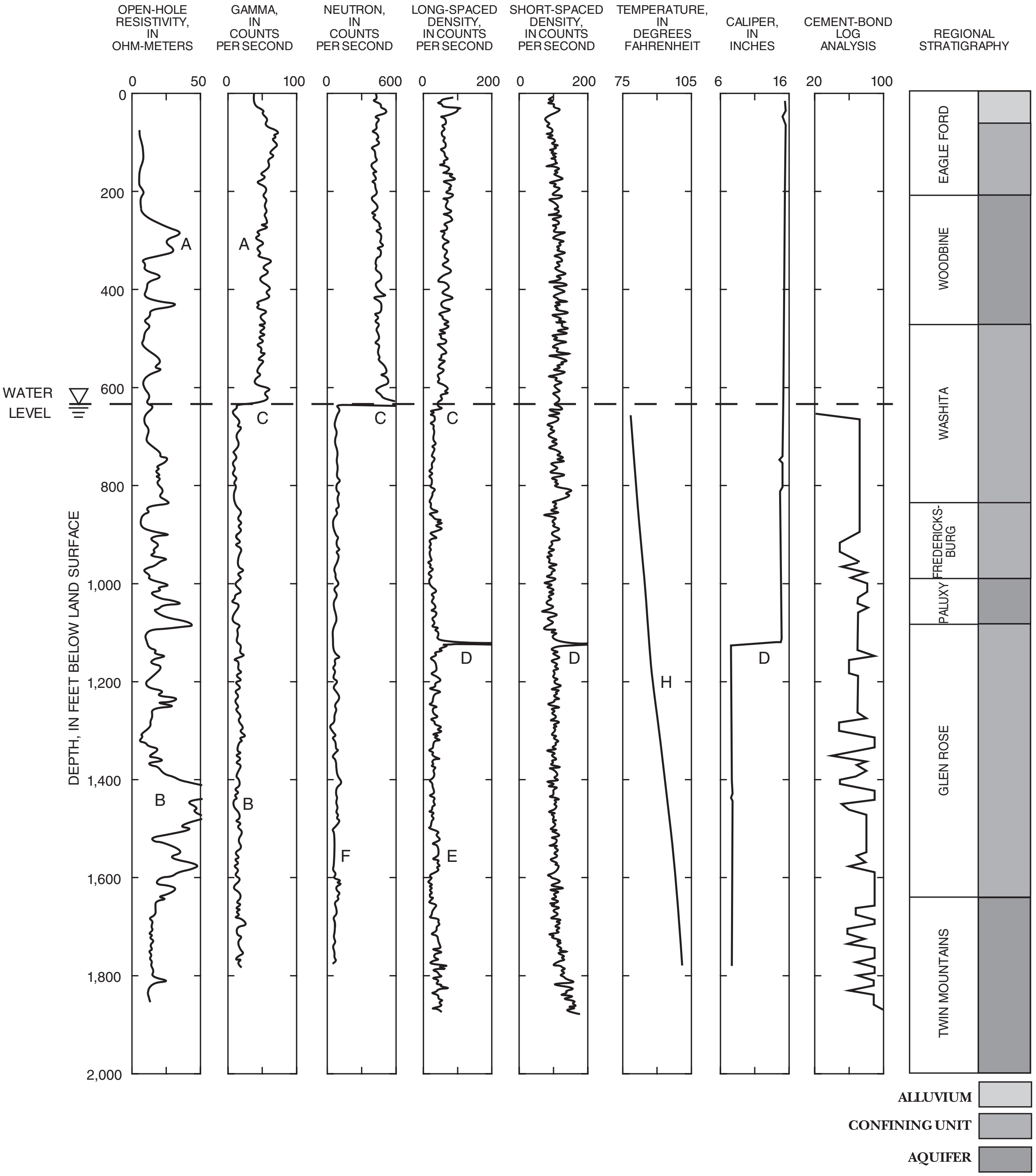

Figure 8. Log composite for well 2A.

be caused by changes in the thermal properties of the surrounding formation. These minor changes in temperature-log gradient do not appear to be associated with intervals of apparent poor cement bonding. In particular, the temperature gradient in well 5A (fig. 11) does not seem appreciably different from the tempera-

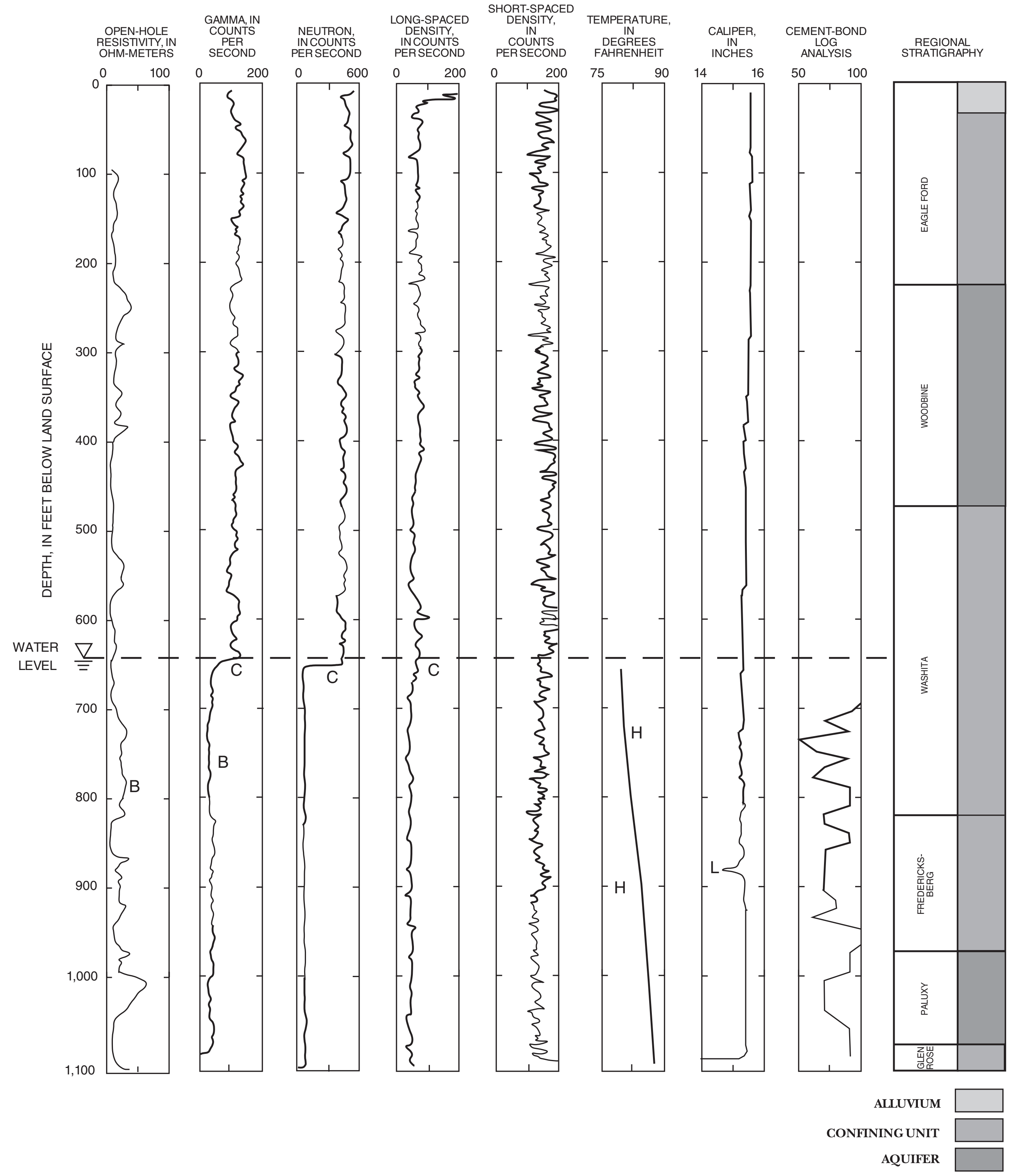

Figure 9. Log composite for well 3A.

ture gradient in well 4A, where the cement bond appears especially good.

The caliper logs indicate borehole walls with no separation of casing at joints. The only noteworthy cal-

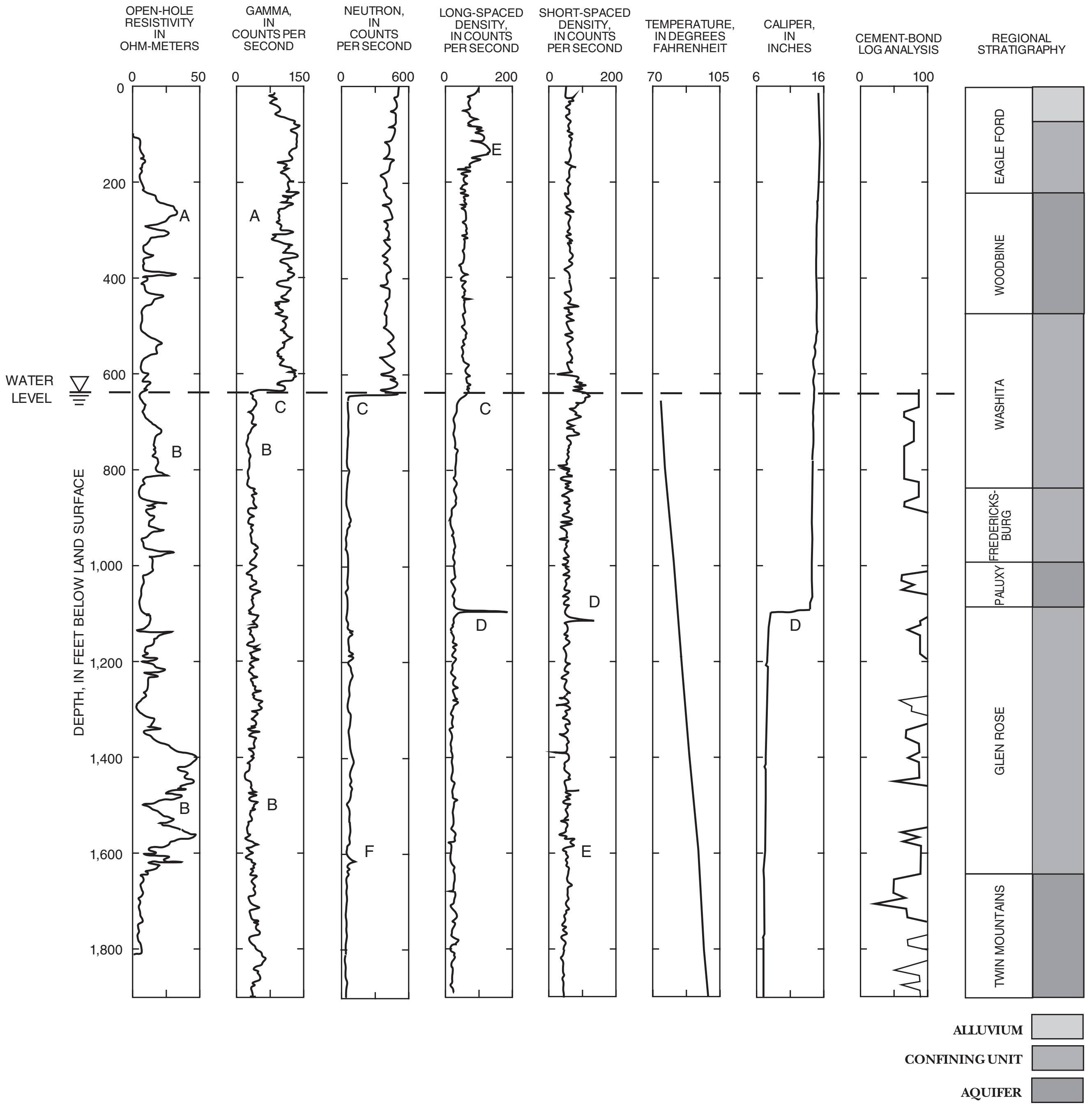

Figure 10. Log composite for well 4A.

iper anomaly is in well 3A, where the caliper log shows a constriction (decrease in borehole diameter; L in fig. 9). The borehole video is of poor quality at this depth, but the constriction appears to be a small cement deposit adhering to the inside of the casing. Such deposits can be formed during the process of installing and cementing the casing and do not affect the integrity of the seal between casing and formation.

The cement-bond analysis shown in figures 7–12 is based on a qualitative interpretation of the acoustic signature logs. One of the main limitations of this analysis is that the analysis gives a circumferentially averaged interpretation, in contrast to the density log,

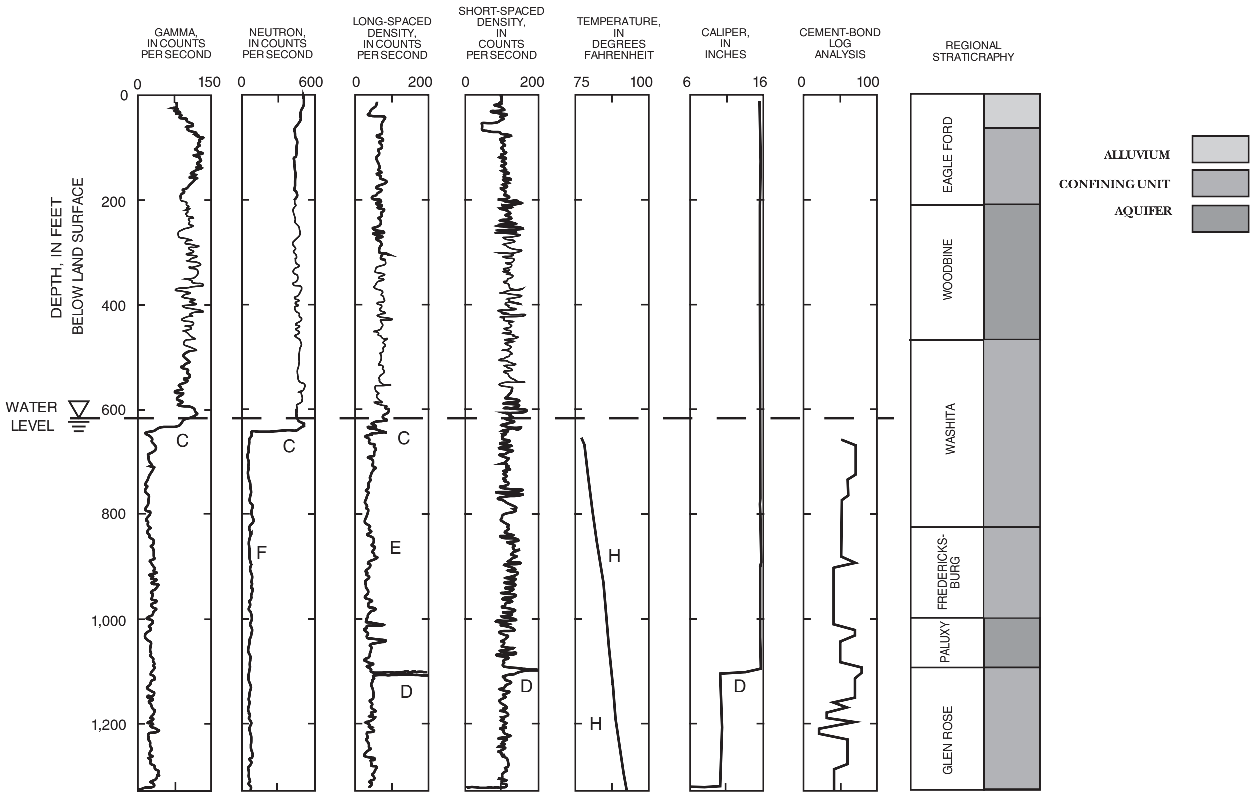

Figure 11. Log composite for well 5A.

which gives a measurement over only a portion of the borehole azimuth. The cement-bond interpretation does indicate that there are some boreholes with better casing bonds than others. For example, the cement-bond log indicates a poor bond from about 700 to 950 ft and from 1,000 to 1,055 ft in depth in well 3A (fig. 9). Other smaller intervals of poor bonding are present in wells 1 and 2A, and the bond appears relatively poor over the entire interval below the water level in well 5A. In general, the acoustic cement-bond log alone does not show the presence of major voids over large depth intervals that could indicate the presence of connected channels behind casing in well 4A and in much of wells 1 and 2A. Because the acoustic measurement averages the signal from the circumference of the borehole, this method is not sensitive to connected channels confined to one side of the borehole. However, it is unlikely that the acoustic signature log and the density log combined would fail to detect the presence of regularly or irregularly distributed voids within the annulus. At the same time the "free pipe" condition indicates only that the casing appears separated from the cement and formation, not how wide that separation is.

The borehole video shows no indication that the interior of the casings have deteriorated appreciably. Although corrosion of the metal was apparent, no holes or gaps in casings were noted. Pictures of the casing above the water are very good, but below the water level the pictures became distorted. Well 1 is the only exception; because this well is used regularly, the water did not contain debris that obscured the view of the casing.

The composited geophysical logs shown in figures 7–12 do not contain temperature or cement-bond analysis data for the well intervals above the water level. The lack of data in this interval poses a special problem because the interpretation of cement-bond conditions is most effective when data from several different logs can be combined. Because the acoustic signature tool does not work in an air-filled borehole and the neutron log indicates water-filled voids, the only geophysical tool expected to be sensitive to voids behind casing in the interval above the static water level is the density tool. The long-spaced density log in the interval above the water level shows variations that correlate with lithology identified from the gamma logs and the electric logs. There is an interval of anomalously high count

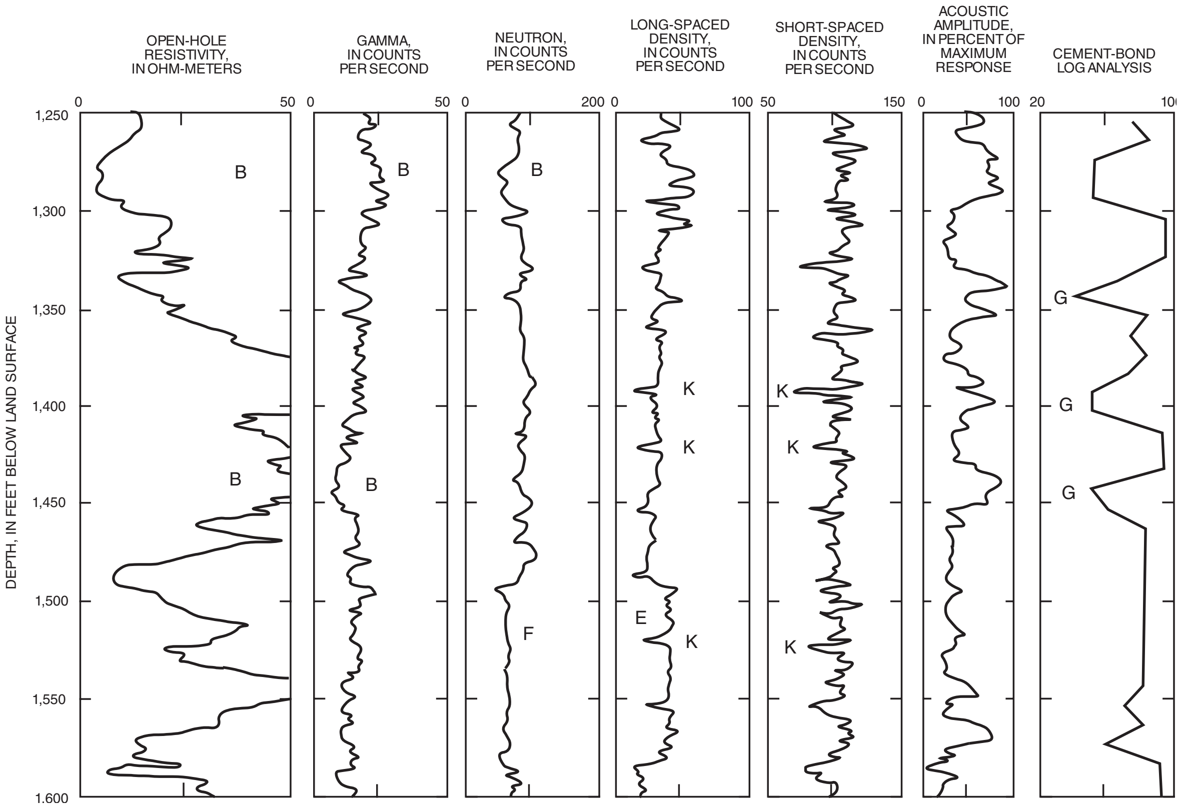

Figure 12. Example of enlarged-scale log composite for well 2A.

rates shown by the long-spaced density detector from about 75 to 175 ft in well 4A. Other than this interval, the density log indicates that there probably are very few intervals with hydraulically conductive channels behind casing above the water level in wells 1, 2A, 3A, 4A, and 5A.

INTEGRITY OF CONFINING UNIT

Borehole geophysical data were used to determine the integrity of the Eagle Ford Shale as a confining unit. Geophysical logs were run in the deep production wells, open-hole electric well logs were reviewed, and a literature search was conducted to describe physical characteristics of the Eagle Ford Shale. Geophysical logs run by the USGS indicate that the thickness of the Eagle Ford Shale ranges from 147 to 185 ft at the NWIRP. Three of the deep production wells at NWIRP have electrical-resistivity logs and two wells have micrologs available. These logs were run in the open boreholes when the wells were drilled. Resistivity logs indicate lithology, whereas micrologs indicate the relative impermeability or "effective porosity" (a measure of the amount of interconnected pore space available for fluid flow and thus an index of permeability) of the formation. The primary use of the microlog is to indicate permeable zones. The probe senses the presence or absence of mud cake, which has a lower resistivity (higher porosity) than the formation. The absence of mud cake indicates impermeable zones because there is no buildup of mud into the formation. The microlog for well 4A shows poor[2] porosity through the entire section of the Eagle Ford Shale. The microlog for well 2A shows one zone of good[2] porosity about 5 ft thick at 164 ft below land surface, whereas the rest of the Eagle Ford Shale section shows poor porosity.

Physical characteristics of the Eagle Ford Shale have been reported by several authors. Allen (1984) described the plasticity index (PI) for the soils derived from the Eagle Ford Shale as ranging from 30 to 80 with most of the samples between 40 and 60 PI. A material is considered highly plastic if the PI is 31 or greater (Sowers, 1979). A plastic material will tend to flow; in the

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[2] Terms "good" and "poor" taken from Schlumberger electric logs (Jay Spence, Vought Aircraft, written commun., 1995).

Table 9. Explanation of letters shown in figures 7–12

Letter	Comment
A	Cased-hole gamma log highs and lows correlate with highs and lows on open-borehole electric logs above the static water level.
B	Cased-hole gamma log highs and lows correlate with highs and lows on open-borehole electric logs below the static water level.
C	Pronounced decreases below the static water level in gamma and neutron count rate associated with mass shield effects of water in the borehole; long-spaced density detector counts are much less affected.
D	Large local anomalies of the long- and short-spaced density detector count rate associated with abrupt diameter change as indicated by caliper log; these anomalies are produced by the large gap between the tool surface and casing as the tool passes the diameter change.
E	Anomalously high long-spaced density detector count rate not associated with lithology and possibly an indication of a void behind casing.
F	Anomalously low neutron count rate associated with anomalously high long-spaced density detector count rate indicating a possible water-filled void behind casing.
G	Very low casing bond score interpreted from the acoustic signature log in the cased borehole indicating a possible water-filled void behind casing.
H	Change in slope on temperature log indicating a depth where thermal properties of adjacent formation changes or where a slight amount of water might be entering or exiting the annulus outside of casing.
I	Pronounced change in slope of temperature log that might indicate the entry or exit of substantial amounts of water from the annulus outside of casing.
J	Nearly isothermal interval of temperature log, indicating that water is flowing in the annular space behind casing (screened interval).
K	Evenly spaced low spikes on the long- and short-spaced density detector count rates indicate the mass of steel casing collars at regular 40-foot intervals.
L	Decrease in casing size, possibly due to cement deposit adhered to inside of casing.

case of the subsurface Eagle Ford Shale, any cracks that develop would be "healed" by this flow. Also, the shale could fill in gaps around casing where cement is sparse. Coffee and others (1980) also refer to the high plasticity and shrink-swell potential of the Eagle Ford Shale. Measurements made by Coffee and others (1980) agree with the ones made by Allen (1984). For the soil types at the NWIRP, the PI was between 35 and 60. In addition to PI, permeability of the soil derived from the Eagle Ford Shale also was measured by Coffee and others (1980) at less than 0.06 in/hr (inches per hour). The low porosity and other physical characteristics of the Eagle Ford Shale make it a relatively impermeable formation that would retard downward migration of contaminants through the unit to underlying aquifers.

SUMMARY AND CONCLUSIONS

The integrity of the production wells and the confining unit at the NWIRP site in Dallas was evaluated using water-quality and borehole geophysical data. Water-quality analysis detected the VOC methylene chloride in samples 1–02 and 2–01. The concentrations in these samples were above the CRQL, but methylene chloride also was detected in the associated lab blank, which could indicate contamination of the sample. Acetone and benzene were detected in sample 2–01, but concentrations were less than the PQL. No SVOCs, PCBs, pesticides, or cyanide were detected at concentrations greater than the CRQL or PQL (except estimated concentrations) in any of the wells. Concentrations were greater than the CRQL and PQL for some trace elements, but leaching from the turbine pumps and metal casings and the static water conditions in the wells could account for the elevated concentrations of these constituents. Tics detected during SVOC laboratory analysis most likely are due to the oil used to lubricate the turbine pumps. In wells 3A and 5A, voids behind casing were more prevalent than in the other wells; however, the laboratory analysis did not detect VOC concentrations greater than the CRQL in samples from those wells.

The geophysical logs for production wells 1, 2A, and 4A show a few locations where local voids behind casing could be present, but none of the evidence indicates that there are long intervals where connected voids could allow flow over substantial distances behind casing. Specifically, the two geophysical logs (density and acoustic signature) most likely to detect the presence of long intervals of voids do not indicate that such voids are present. The compensated density log is sensitive to voids along the part of the borehole circumference surveyed by that logging tool. The acoustic signature log gives an averaged signal from the circumference of the borehole that might not indicate a void confined to only one side of the borehole. However, it is unlikely that both of these tools would fail to indicate the presence of long intervals containing voids irregularly distributed within the annulus or consistently confined to one side of the annulus. Although the cement-bond log only works in the water-filled part of the well, the aquifers of concern are at depths greater than the water level in each well. Therefore, if voids are present above the water column and were not detected by the density log, any downward migration of contaminants would be stopped at the first area of complete bonding.

Wells 3A and 5A show poor bonding over most of the interval logged. The cement-bond log analysis for those wells could indicate the presence of interconnected channels over long vertical distances. Although the possible presence of channels indicates the well integrity is in question, the water-quality data do not indicate the presence of target compounds in the water column of the production wells. In addition, the temperature log does not indicate flow behind casing in these wells.

The caliper log indicates that there are no separations in casing, and the temperature logs generally indicate that there is no major movement of water in the annulus. The one exception is the interval near the bottom of well 1 where the temperature log definitely does indicate flow behind casing. This area is in the screened interval of well 1, where flow behind casing is likely to occur. This one instance of documented effects of flow on the temperature log indicates that other instances would be detectable if they in fact had occurred.

Historical and new geophysical data as well as the literature indicate that the Eagle Ford Shale is an excellent confining unit composed mainly of clays with a high plasticity index and low permeability. The resistivity, gamma, and neutron logs indicated that the Eagle Ford Shale ranges from 147 to 185 ft thick in the study area. The thickness of the unit and the physical characteristics of the impermeable clays indicate that the Eagle Ford Shale could act as a deterrent to migration of TCE, DCE, VC, chromium, lead, or other contaminants in the shallow alluvial aquifer to deeper aquifers.

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