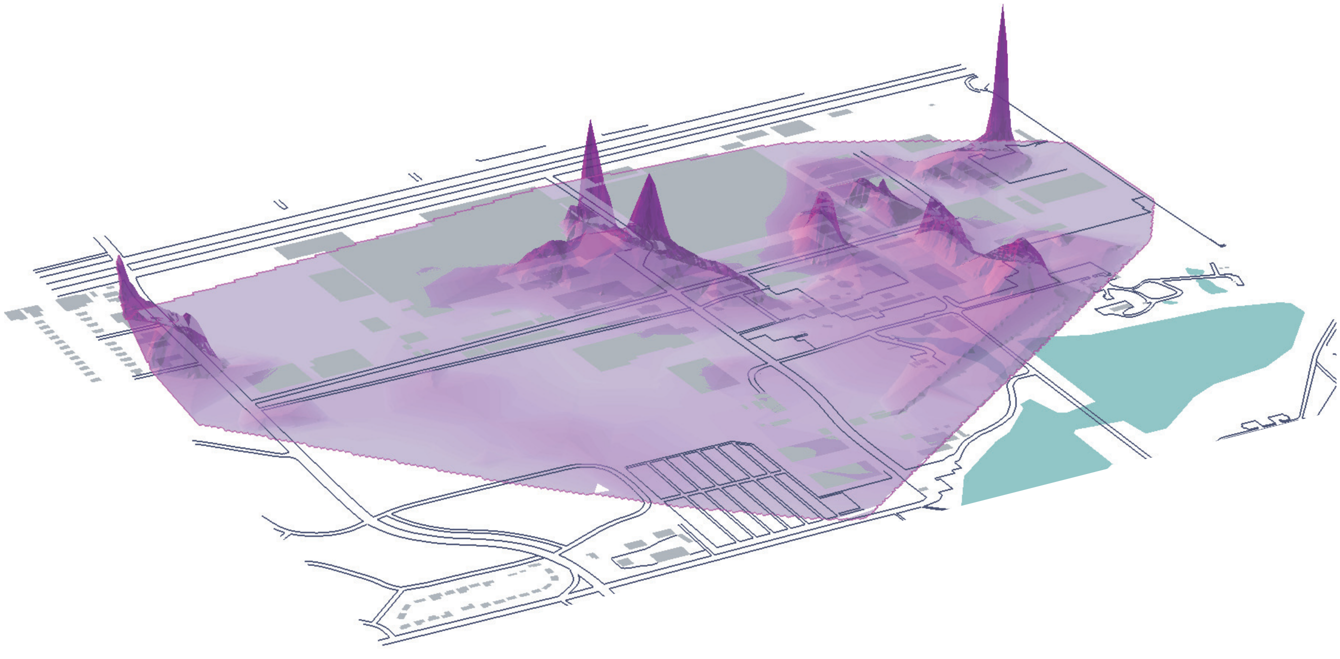
In cooperation with the Southern Division Naval Facilities Engineering Command

Oxidation-Reduction Processes in Ground Water at Naval Weapons Industrial Reserve Plant, Dallas, Texas

Water-Resources Investigations Report 03–4046



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U.S. GEOLOGICAL SURVEY
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Engineering Command

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Gale A. Norton, Secretary

U.S. GEOLOGICAL SURVEY

Charles G. Groat, Director

For additional information write to

District Chief
U.S. Geological Survey
8027 Exchange Dr.
Austin, TX 78754–4733
E-mail: dc_tx@usgs.gov

Copies of this report can be purchased from

U.S. Geological Survey
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ABBREVIATIONS AND VERTICAL DATUM

°C, degree Celsius
ft, foot
ft/ft, foot per foot
ft/mi, foot per mile
gal/min, gallon per minute
in., inch
µg/L, microgram per liter
mg/L, milligram per liter
mL, milliliter
mL/min, milliliter per minute
nm, nanometer
nM, nanomolar

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

Oxidation-Reduction Processes in Ground Water at Naval Weapons Industrial Reserve Plant, Dallas, Texas

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Abstract

Concentrations of trichloroethene in ground water at the Naval Weapons Industrial Reserve Plant in Dallas, Texas, indicate three source areas of chlorinated solvents—building 1, building 6, and an off-site source west of the facility. The presence of daughter products of reductive dechlorination of trichloroethene, which were not used at the facility, south and southwest of the source areas are evidence that reductive dechlorination is occurring. In places south of the source areas, dissolved oxygen concentrations indicated that reduction of oxygen could be the dominant process, particularly south of building 6; but elevated dissolved oxygen concentrations south of building 6 might be caused by a leaking water or sewer pipe. The nitrite data indicate that denitrification is occurring in places; however, dissolved hydrogen concentrations indicate that iron reduction is the dominant process south of building 6. The distributions of ferrous iron indicate that iron reduction is occurring in places south-southwest of buildings 6 and 1; dissolved hydrogen concentrations generally support the interpretation that iron reduction is the dominant process in those places. The generally low concentrations of sulfide indicate that sulfate reduction is not a key process in most sampled areas, an interpretation that is supported by dissolved hydrogen concentrations. Ferrous iron and dissolved hydrogen concentrations indicate that ferric iron reduction is the primary oxidation-reduction process. Application of mean first-order decay rates in iron-reducing conditions for trichloroethene, dichloroethene, and vinyl chloride yielded half-lives for those solvents of 231, 347, and 2.67 days, respectively. Decay rates, and thus half-lives, at the facility are expected to be similar to those computed. A weighted scoring method to indicate sites where reductive dechlorination might be likely to occur indicated strong evidence for anaerobic biodegradation of chlorinated solvents at six sites. In general, scores were highest for samples collected on the northeast side of the facility.

INTRODUCTION

The Naval Weapons Industrial Reserve Plant (NWIRP) in Dallas, Tex., has been in operation since 1941. The 314-acre NWIRP facility, which currently (2002) is operated by Vought Aircraft Industries Inc., manufactures military and commercial aircraft and aircraft components. Manufacturing processes associated with the facility's operation include metal machining and treating; fabrication, painting, and stripping of aircraft or aircraft parts; and aircraft renovation. These processes use petroleum products and solvents and create wastes that include oils and fuels, chlorinated solvents, construction debris, and metals. The chlorinated ethenes trichloroethene (TCE), 1,2-*cis*-dichloroethene (*cis*-DCE), 1,2-*trans*-dichloroethene (*trans*-DCE), and vinyl chloride (VC) as well as chlorinated ethanes have been detected at various locations in the shallow alluvial deposits at the site (EnSafe/Allen & Hoshall, 1994, 1996). Multiple ground-water contamination plumes exist in the shallow alluvial deposits at the site because of several source areas (EnSafe/Allen & Hoshall, 1996). Presently, the facility is operating under a Resource Conservation and Recovery Act Part B permit.

Purpose and Scope

This report describes the oxidation-reduction (redox) processes in ground water at NWIRP on the basis of data collected and analyzed by the U.S. Geological Survey (USGS) and private companies. The USGS collected ground-water samples from 51 wells in September 1997 and from 57 wells in March 1998 (table 1, at end of report). The USGS analyzed the September 1997 samples in the field for specific conductance, pH, temperature, dissolved oxygen (DO), ferrous iron, total iron, sulfide, carbon dioxide, methane, and hydrogen; the March 1998 samples were analyzed in the field for specific conductance, pH, temperature, bicarbonate alkalinity, and selected volatile organic compounds (VOCs). The USGS sent September 1997 samples to Quanterra Laboratories for analysis of bicarbonate alkalinity; sulfate; chloride; fluoride; silica; nitrate, nitrate plus nitrite, and ammonia nitrogen; orthophosphate phosphorus; boron; and total organic carbon (TOC). EnSafe/Allen & Hoshall (hereinafter, EnSafe), a consultant to the Navy, collected ground-water samples from about 150 wells and had them analyzed by a contract laboratory for selected VOCs and metals in September 1997.

Description of Study Area

The study area is in the southwestern corner of the city of Dallas (fig. 1). NWIRP is located north of Cottonwood Bay, which is a part of Mountain Creek Lake. The climate in north-central Texas is characterized by long, hot summers and short, mild winters. The average annual precipitation in north-central Texas is 32 in., with most of the precipitation occurring during spring and fall. Land-surface altitudes at NWIRP range from about 500 to 460 ft above sea level west to east and north to south (fig. 1). Stormwater runoff drains into a manmade channel of Mountain Creek Lake locally referred to as Cottonwood Bay.

Hydrogeology

NWIRP is located on shallow alluvial deposits about 40 to 80 ft above the present-day flood plain of the West Fork Trinity River. The alluvial deposits range from about 10 to 75 ft thick and overlie the Cretaceous-age Eagle Ford Shale (EnSafe/Allen & Hoshall, 1994). A previous study used borehole geophysical logging and cone penetrometer data to map the relative permeability of the shallow alluvial deposits at the NWIRP site (Anaya and others, 2000; Braun and others, 2000). In that study, the shallow alluvial deposits were divided into upper, middle, and lower parts of roughly equal thickness. A series of intersecting sections was developed (Anaya and others, 2000, pls. 1–3), which indicates that the shallow alluvial deposits occur as lenticular, interfingering beds of sand, silt, and clay atop the shale bedrock. The relative permeability of the beds is gradational and depends on the amounts of sand (most permeable), silt, and clay (least permeable) present (fig. 2). The shallow alluvial deposits have been replaced by permeable fill material in places.

Ground water generally moves downgradient from a recharge area in the northwestern part of the study area through the shallow alluvial deposits underlying NWIRP toward the principal discharge area to the southeast, Cottonwood Bay (fig. 3). Lateral flow gradients steepen from about 25 ft/mi in the north to about 75 ft/mi in the south. Downward vertical gradients (as much as 0.5 ft/ft under natural conditions) indicate that some water migrates between upper and lower parts of the shallow alluvial deposits. Downward migration is greatest in the northern part of the study area. Upward gradients near the east lagoon, west lagoon, and along the northern shore of Cottonwood Bay (fig. 3) indicate diffuse ground-water discharge to these topographically low areas (Barker and Braun, 2000). Specific-capacity tests at more than 20 wells produced 1.5 to 2.0 gal/min of sustained flow from each well (EnSafe/Allen & Hoshall, 1994). About 76 percent of NWIRP ground cover is impervious; most of the pervious (grassy) areas are near the south end of the facility adjacent to Cottonwood Bay (Barker and Braun, 2000).

SAMPLING AND ANALYTICAL METHODS AND RESULTS

Unfiltered ground-water samples were collected from wells using a peristaltic pump. Wells were pumped for at least 30 minutes before sampling. Constituents listed in table 2 (at end of report) were analyzed in the field or in the laboratory as indicated. The appendix lists selected additional data collected at NWIRP.

Decontamination procedures consisted of equipment cleaning and rinsing between wells using deionized water, methanol (as needed), and a dilute detergent solution (as needed). Equipment cleaned included glass bubblers for headspace analyses, monitoring probes, and glassware used with the HACH colorimeters. New Teflon and Tygon tubing was used for each well.

Volatile Organic Compounds

VOC samples were collected by EnSafe in September 1997 and analyzed by a contract laboratory using the U.S. Environmental Protection Agency (1999) method 8260. The USGS collected samples and

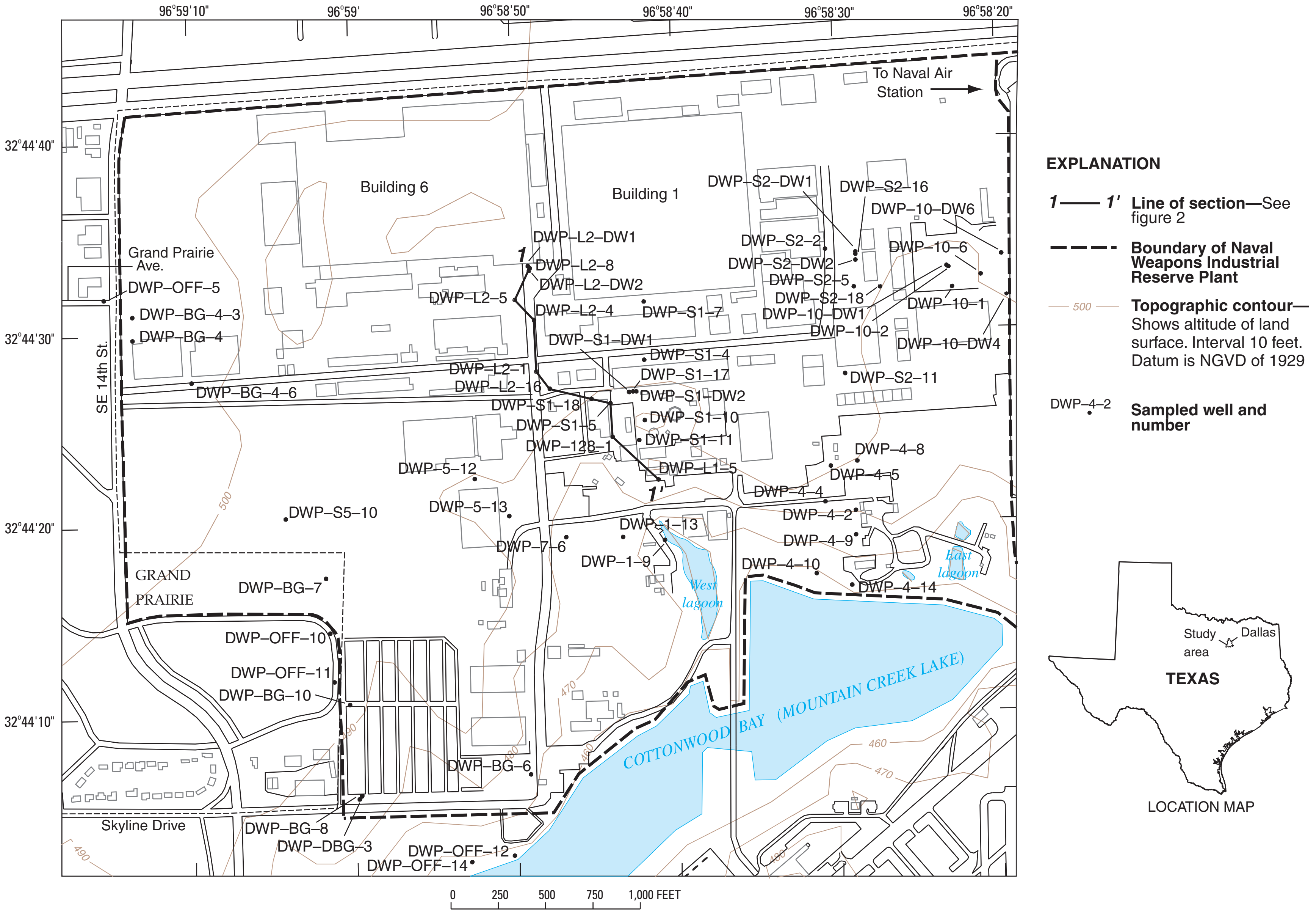


Figure 1. Location of study area, wells sampled, and lithologic cross section *1–1'* at the Naval Weapons Industrial Reserve Plant, Dallas, Texas.

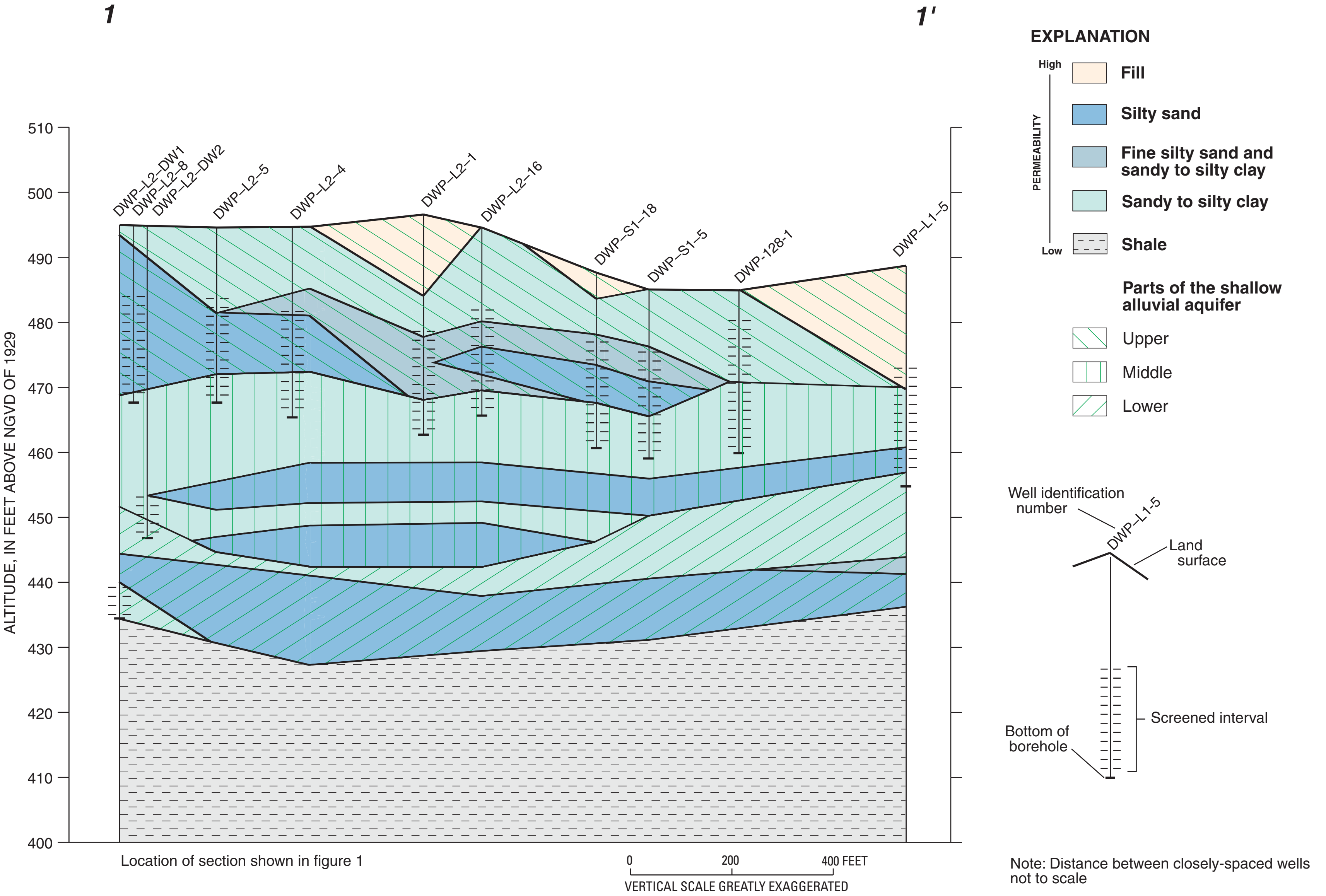
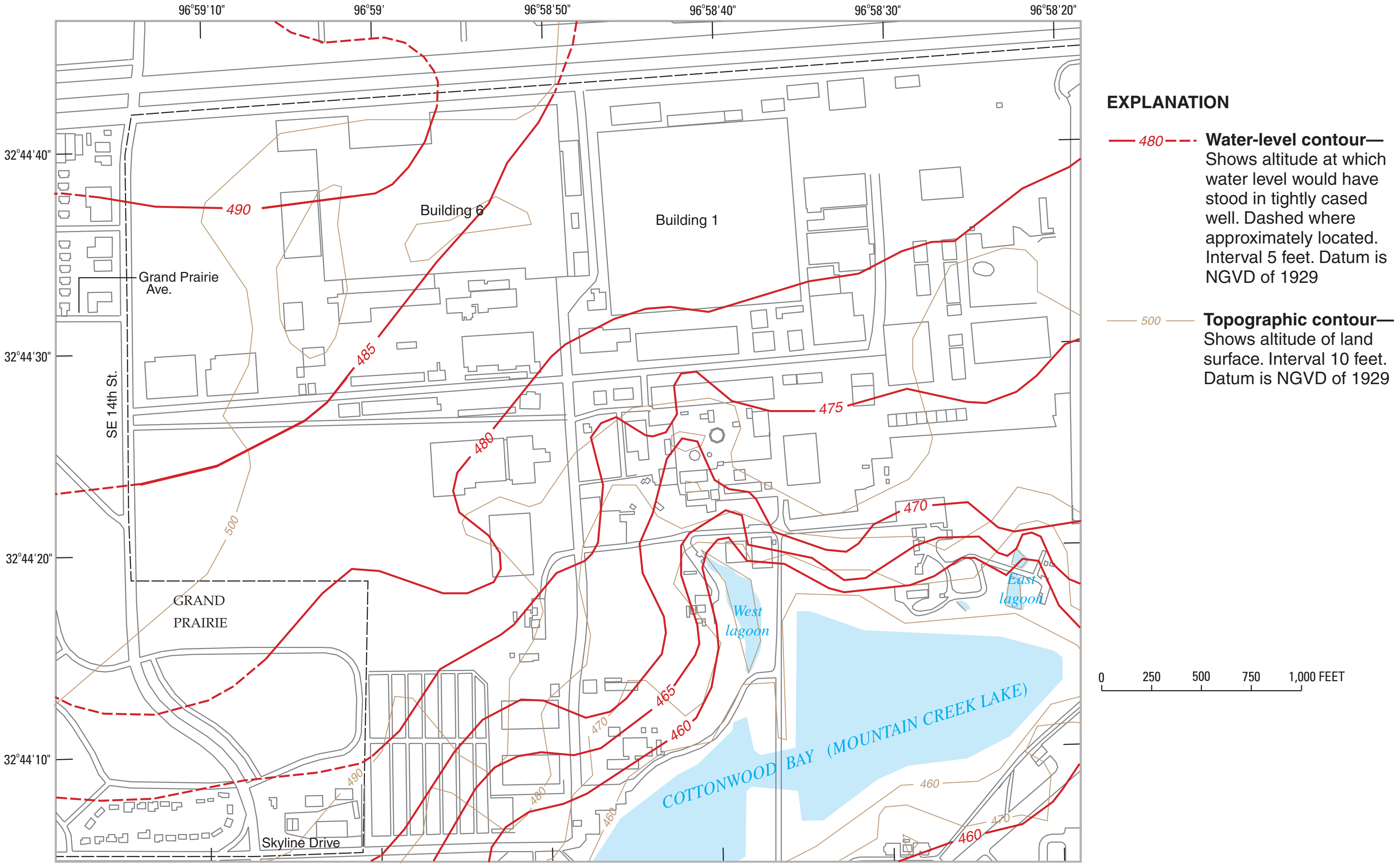


Figure 2. Lithologic section *1–1′* at the Naval Weapons Industrial Reserve Plant, Dallas, Texas (modified from Anaya and others, 2000; Braun and others, 2000).



Modified from Barker and Braun, 2000, figure 20 (water levels), figure 2 (topography)

Figure 3. Water-level altitudes in shallow alluvial deposits at the Naval Weapons Industrial Reserve Plant, Dallas, Texas, March 1998.

analyzed them with a field gas chromatograph (GC) in March 1998. The field GC results are considered semi-quantitative but compare relatively well with the laboratory data. Samples analyzed in the field were collected in a 40-mL vial. At each well, 20 mL of sample was collected in the vial. The vial was placed in a water bath and brought to 30 °C, the vial was shaken vigorously, and a quantity of headspace was removed with a gas-tight syringe and injected into a Photovac 10S50 GC calibrated for TCE, *cis*-DCE, *trans*-DCE, and VC. Results of both laboratory and field GC analyses are listed in table 3 (at end of report).

Dissolved Oxygen

The concentration of DO was measured in the field using the indigo carmine method (Gilbert and others, 1982). Ground water was pumped through Teflon tubing (having a low oxygen-diffusion coefficient) into a sampling cell. An ampoule was placed into the overflowing sample cell, and the tip was broken to draw a fixed size of sample into the ampoule. The tip was covered to ensure against atmospheric contamination of the sample. The ampoule was inverted carefully several times to mix the color-developing reagents with the sample and allowed to react for 2 minutes. The ampoule then was placed in a CHEMetrics VVR photometer, and the DO concentration was recorded. The method detection limit for DO was 0.05 mg/L. Results of DO analyses are listed in table 4 (at end of report).

Nitrate and Nitrite

Nitrate as nitrogen and nitrate plus nitrite as nitrogen samples were collected by the USGS in September 1997 and analyzed by Quanterra Laboratories using methods 300.0 and 353.2 (U.S. Environmental Protection Agency, 1993 and 1983, respectively). Nitrite concentrations are listed in table 4. Nitrate and nitrate plus nitrite concentrations are listed in the appendix.

Ferrous Iron and Total Iron

The concentration of ferrous iron was measured using the HACH phenanthroline powder pillow method (255), and the concentration of total iron was measured using the HACH FerroVer colorimetric method (265) (HACH Co., 1989). For ferrous and total iron, 25 mL of ground water was poured into each of four colorimetric vials. The ferrous and total iron reagents, respectively, were then added to the first and second sample vials; the vials were filled with sample and allowed to react for 3 minutes. The third and fourth sample vials (the blanks) were placed in a DR2000 spectrophotometer, and the zero concentration was set at a 510-nm wavelength. The blank vials were removed, and each ground-water-sample vial was placed in the spectrophotometer; after 3 minutes, concentrations of ferrous and total iron, in milligrams per liter, were recorded. The lower and upper method detection limits for ferrous and total iron using the methods and instrumentation listed above were 0.01 and 3 mg/L, respectively. If a sample concentration was greater than 3 mg/L, a 50-percent dilution of the sample with deionized (DI) water was used, and the sample was re-analyzed. Several of the ferrous iron samples collected in September 1997 became cloudy during color development, causing incorrect readings on the spectrophotometer. The concentrations reported for cloudy ferrous samples in table 4 are qualified.

Sulfate and Sulfide

Sulfate samples were collected by the USGS in September 1997 and analyzed by Quanterra Laboratories (appendix). The concentration of sulfide was measured using the HACH methylene blue colorimetric method (690) (HACH Co., 1989). For sulfide a 25 mL sample of ground water was collected into a sample cell, and a second sample cell was filled with DI water. One mL of sulfide reagent 1 was added to each sample cell and swirled to mix. After mixing, 1 mL of sulfide reagent 2 was immediately added to each vial and swirled to mix. The methylene blue color was allowed to develop for 5 minutes. After 5 minutes, the blank sample was placed into the DR2000 spectrophotometer, and the zero concentration was set at a 665-nm wavelength. The blank sample cell was removed, the sample cell containing the ground-water sample was placed in the colorimeter, and the concentration of sulfide, in milligrams per liter, was recorded. The lower and upper method detection limits for sulfide using the method and instrumentation listed above were 0.001 and 0.6 mg/L, respectively. Sulfide concentrations are listed in table 4.

Dissolved Hydrogen

The concentration of dissolved hydrogen was measured using the "bubble strip" method (Chapelle, 1996) in which ground water was pumped through a glass bubbler fitted with a septum. Once flow was established at about 500 mL/min and the bubbler was filled and free of gas bubbles, 20 mL of hydrogen-free helium was injected. The induced headspace was allowed to equilibrate with the flowing ground water for about 30 minutes. After 30 minutes, 10 mL of the headspace gas was withdrawn using a 10-mL gas-tight syringe with valve; after 5 minutes, a second 10-mL sample of the headspace gas was withdrawn into a second syringe. Both samples were analyzed for hydrogen using a reducing gas detector chromatograph (Trace Analytical, 1997) calibrated with standard gases. Dissolved hydrogen concentrations listed in table 4 are an average of the two measurements.

Total Organic Carbon

TOC samples were collected by the USGS in September 1997 and analyzed by Quanterra Laboratories using method 9060 (U.S. Environmental Protection Agency, 1999). TOC concentrations are listed in the appendix.

OXIDATION-REDUCTION PROCESSES

The most common redox processes in ground water are the reduction of oxygen, nitrate (denitrification), ferric iron, sulfate, and carbon dioxide (methanogenesis). The reduced chemical species produced during redox reactions are used in biological processes that facilitate reductive dechlorination of chlorinated solvents. The efficiency of the reductive dechlorination process varies depending on redox conditions. Dechlorination of the more highly chlorinated solvents (tetrachloroethene [PCE], TCE, and DCE) can occur in mildly reducing environments, such as those associated with ferric iron reduction, but dechlorination is more efficient in sulfate-reducing or methanogenic conditions (Chapelle, 1996; Suarez and Rifai, 1999). VC typically requires a more strongly reducing environment such as methanogenesis to degrade but also will degrade under iron-reducing conditions and under aerobic conditions (Bradley and Chapelle, 1998). Table 5 (at end of report) lists mean first-order decay rates for TCE, DCE, and VC under five redox conditions and the computed half-lives associated with the respective decay rates. In general, the larger the first-order decay rate, the more efficient the reductive dechlorination process.

Hydrogen is produced during anaerobic microbial metabolism. It is then used by respirative microorganisms that most commonly use ferric iron, sulfate, or carbon dioxide as electron acceptors. Dissolved hydrogen concentrations can be used to identify which redox process is dominant at a particular location (fig. 4). Of the reducing environments noted above, methanogenesis consumes the least hydrogen. Hydrogen concentrations in ground water are expected to be greater than 5.0 nM under methanogenic conditions. If sulfate reduction is the dominant redox process, hydrogen concentrations will range from 1.0 to 4.0 nM. If ferric iron reduction is the dominant redox process, hydrogen concentrations will range from 0.2 to 0.8 nM. If denitrification is the dominant redox process, hydrogen concentrations will be less than 0.1 nM (Chapelle, 1996).

In addition to dissolved hydrogen concentrations, concentrations of the reduced species nitrite, ferrous iron, sulfide, and methane are useful for identifying redox processes. In some cases, determination of dissolved hydrogen concentrations might not be necessary; but when concentrations of the reduced species produce conflicting information, hydrogen concentrations are critical. For example, ferrous iron, sulfide, and methane can be transported by ground-water flow in the subsurface. The constituents could be produced upgradient and transported to the well where the measurement is made. To determine which redox process is dominant at the well where the measurement is made, dissolved hydrogen concentrations are needed.

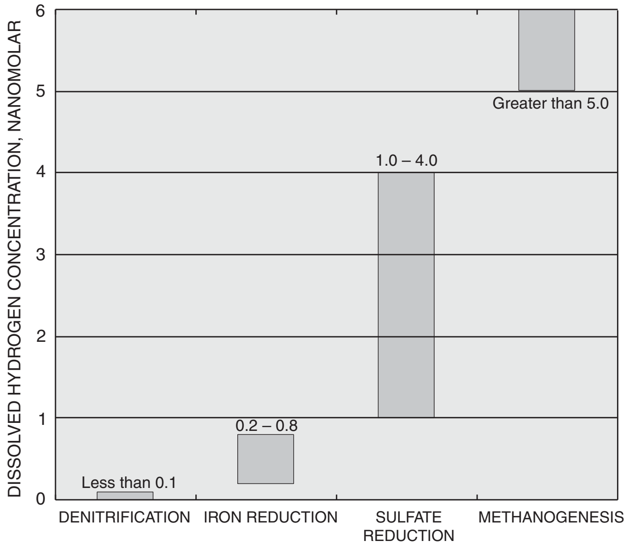


Figure 4. Dissolved hydrogen concentrations associated with oxidation-reduction processes in ground water (modified from Chapelle, 1996).

Volatile Organic Compounds

The concentrations of chlorinated solvents at NWIRP are controlled partially by reductive dechlorination, which in turn is controlled by redox processes in ground water. Under anaerobic conditions, reductive dechlorination of TCE proceeds as follows:

$$\text{TCE} \Rightarrow \textit{cis}\text{-DCE} + \text{Cl} \Rightarrow \text{VC} + 2\text{Cl} \Rightarrow \text{ethene} + 3\text{Cl}. \quad (1)$$

The presence of *cis*-DCE and VC usually indicates that reductive dechlorination of TCE is occurring. Normally *cis*-DCE is not used as a primary solvent. It is more commonly a product of the degradation of a more highly chlorinated compound. Neither *cis*-DCE nor VC was used at NWIRP (EnSafe/Allen & Hoshall, 1996). Therefore, the presence of these daughter products indicates that TCE is degrading. The presence of VC indicates that *cis*-DCE is degrading; but it also indicates that complete reductive dechlorination (eq. 1) might not be occurring in all areas of the facility. Figures 5, 6, and 7 show the distributions of TCE, *cis*-DCE, and VC, respectively, in shallow ground water at NWIRP. These maps were created using data collected by EnSafe in September 1997 from about 150 wells. Most of the wells were screened in the upper part of the shallow alluvial deposits only; some were screened in the upper and middle parts; and a few were screened in the middle and (or) lower part. The high dilution factors used during laboratory analyses might have masked smaller concentrations of VC in some samples. Concentrations less than the method detection limit were not used in the generation of the concentration maps.

The three primary source areas for chlorinated solvents in ground water at NWIRP are building 1, building 6, and an off-site source west of the facility. Concentrations of chlorinated solvents are highest near these areas (figs. 5, 6, and 7). Each of three plumes (one from each source area) has distinctly different chemistry with respect to chlorinated solvents. The plume originating from the building 1 area contains chlorinated ethenes and chlorinated ethanes including trichloroethane and 1,1-dichloroethane (appendix). The plume originating from the building 6 area primarily is composed of chlorinated ethenes. The source area of building 6 generally has a larger TCE/*cis*-DCE ratio than other areas of NWIRP. Larger ratios generally indicate that reductive dechlorination is less efficient than in areas where the ratio is smaller. The plume that originates off-site is the only plume in which PCE concentrations are greater than 10 μg/L. Wells DWP–OFF–5, DWP–BG–4, and DWP–BG–4–3 had PCE concentrations of 170, 98, and 43 μg/L, respectively (appendix).

Dissolved Oxygen

DO concentrations greater than about 0.50 mg/L indicate that oxygen reduction is the dominant microbial process (U.S. Environmental Protection Agency, 1998). Oxygen reduction occurs as follows:

$$CH_2O + O_2 \Rightarrow CO_2 + H_2O. \quad (2)$$

Ground water is unconfined in shallow alluvial deposits at NWIRP, and both anaerobic (DO less than 0.50 mg/L) and aerobic (DO greater than 0.50 mg/L) (U.S. Environmental Protection Agency, 1998) groundwater conditions were observed at various locations. DO concentrations tended to be less than 1.00 mg/L but were as high as 2.29 mg/L (table 4); the mean concentration was 0.55 mg/L for samples collected in September 1997 and 0.35 mg/L for samples collected in March 1998. Several wells sampled south of building 6, a primary source area, had DO concentrations greater than 1.00 mg/L during both sampling events (figs. 8, 9). These concentrations are higher than would be expected near the source of a plume. One possible explanation is a leaking underground water or sewer pipe. Barker and Braun (2000) indicated that near the area where DO concentrations are larger, recharge was added to a ground-water-flow model of NWIRP to simulate an additional source of water other than infiltration of precipitation. The authors believe the observed DO concentrations more likely are related to an inflow of water rather than oxygen reduction. In general, the distribution of DO was similar for September 1997 and March 1998.

Nitrate and Nitrite

Nitrate is reduced to nitrite as follows:

$$CH_2O + 2NO_3^- \Rightarrow 2NO_2^- + CO_2 + H_2O. \quad (3)$$

Because of this process, an increase in nitrite would be expected where nitrate reduction is occurring. The mean concentration of nitrite in those samples containing nitrite collected in September 1997 was 0.36 mg/L. The nitrite data indicate that nitrate reduction is occurring in places. Nitrite concentrations equal to or greater than 0.5 mg/L were detected in six wells (screened in the upper or in the upper and middle parts of the shallow alluvial deposits)—DWP–4–2, DWP–4–4, DWP–4–9, DWP–L2–1, DWP–L2–16, and

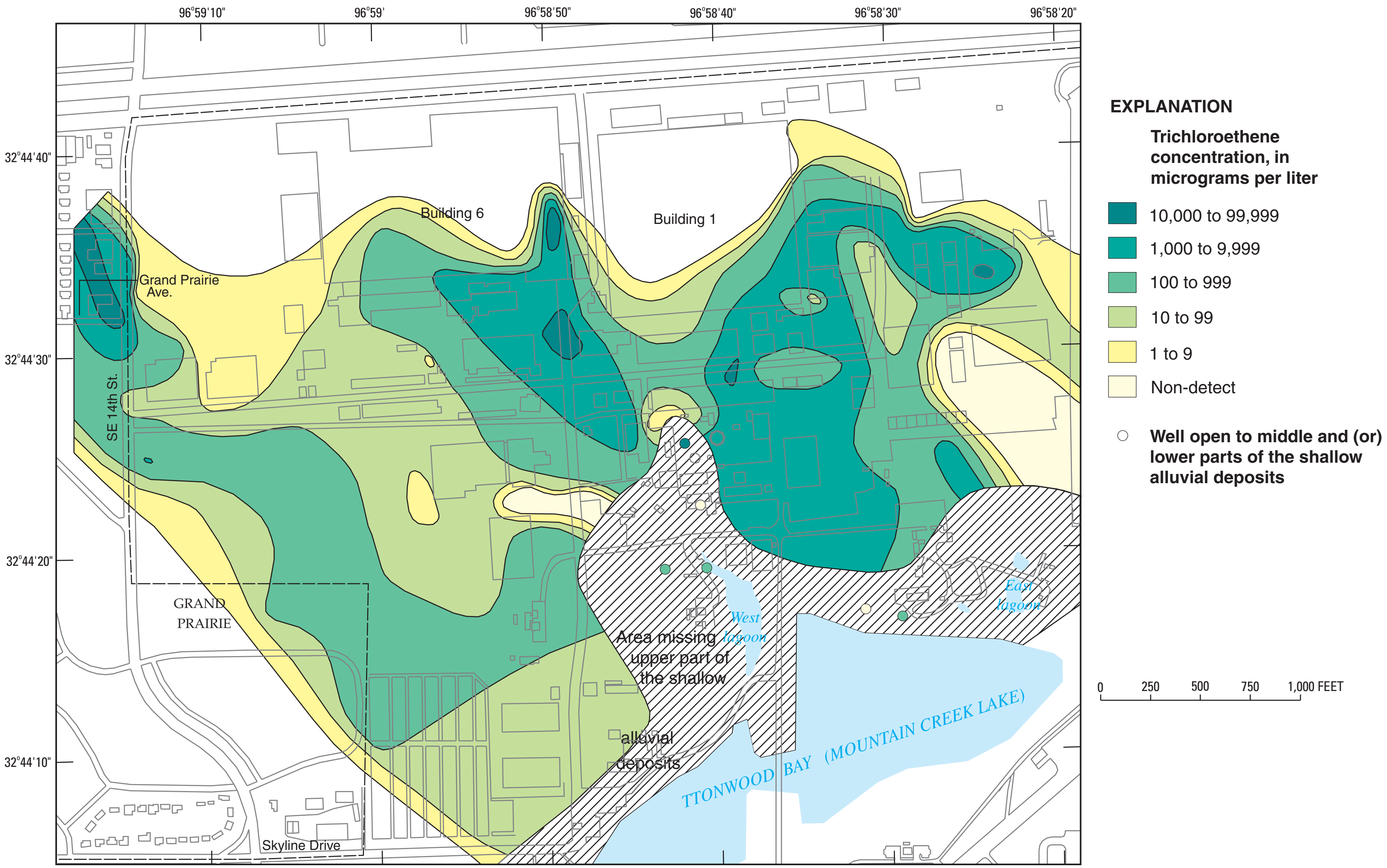


Figure 5. Trichloroethene concentrations from wells screened in the upper or in the upper and middle parts of the shallow alluvial deposits at the Naval Weapons Industrial Reserve Plant, Dallas, Texas, September 1997. (Concentration datapoints provided by EnSafe/Allen & Hoshall.)

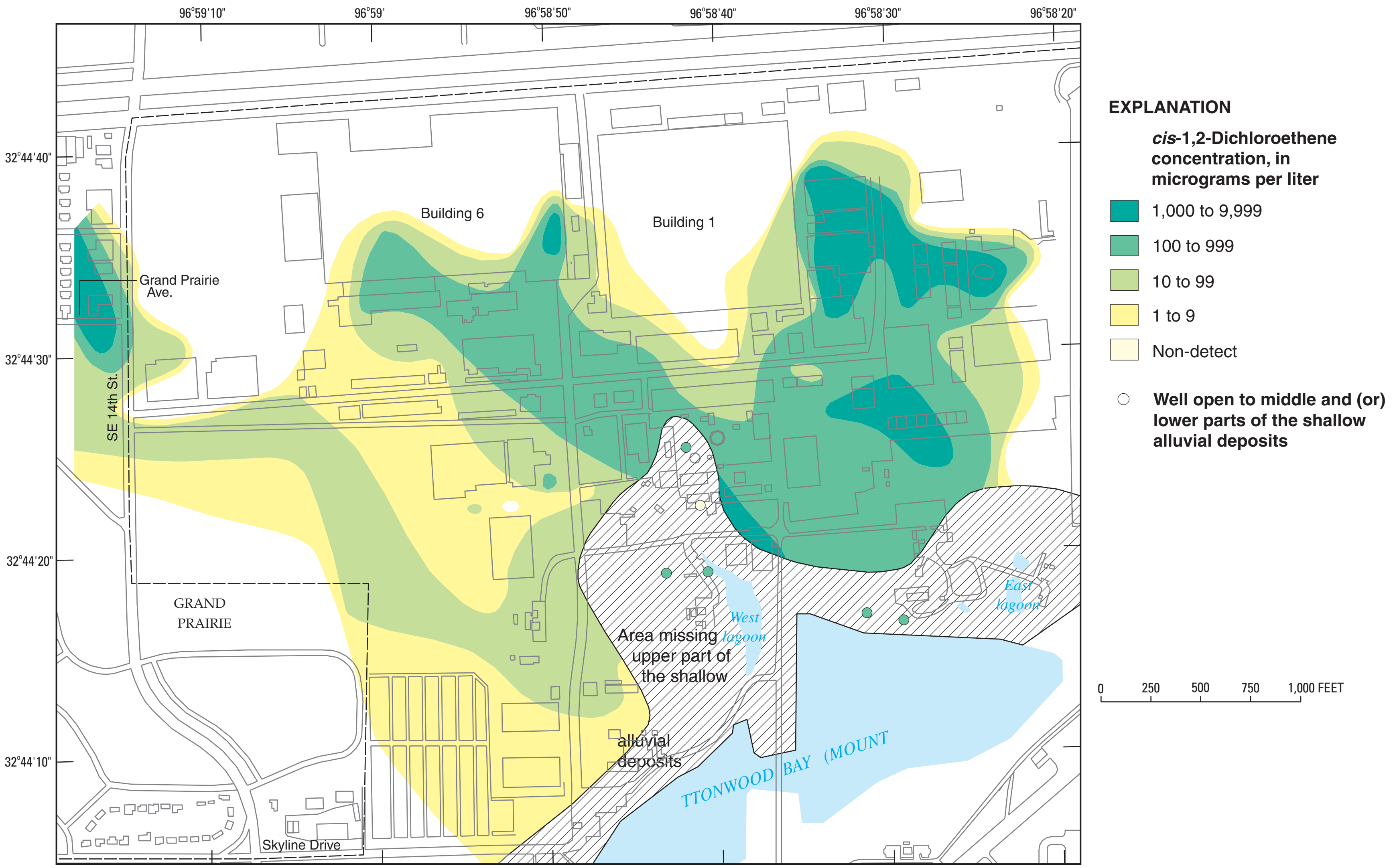


Figure 6. *cis*-1,2-Dichloroethene concentrations from wells screened in the upper or in the upper and middle parts of the shallow alluvial deposits at the Naval Weapons Industrial Reserve Plant, Dallas, Texas, September 1997. (Concentration datapoints provided by EnSafe/Allen & Hoshall.)

Figure 7. Vinyl chloride concentrations from wells screened in the upper or in the upper and middle parts of the shallow alluvial deposits at the Naval Weapons Industrial Reserve Plant, Dallas, Texas, September 1997. (Concentration datapoints provided by EnSafe/Allen & Hoshall.)

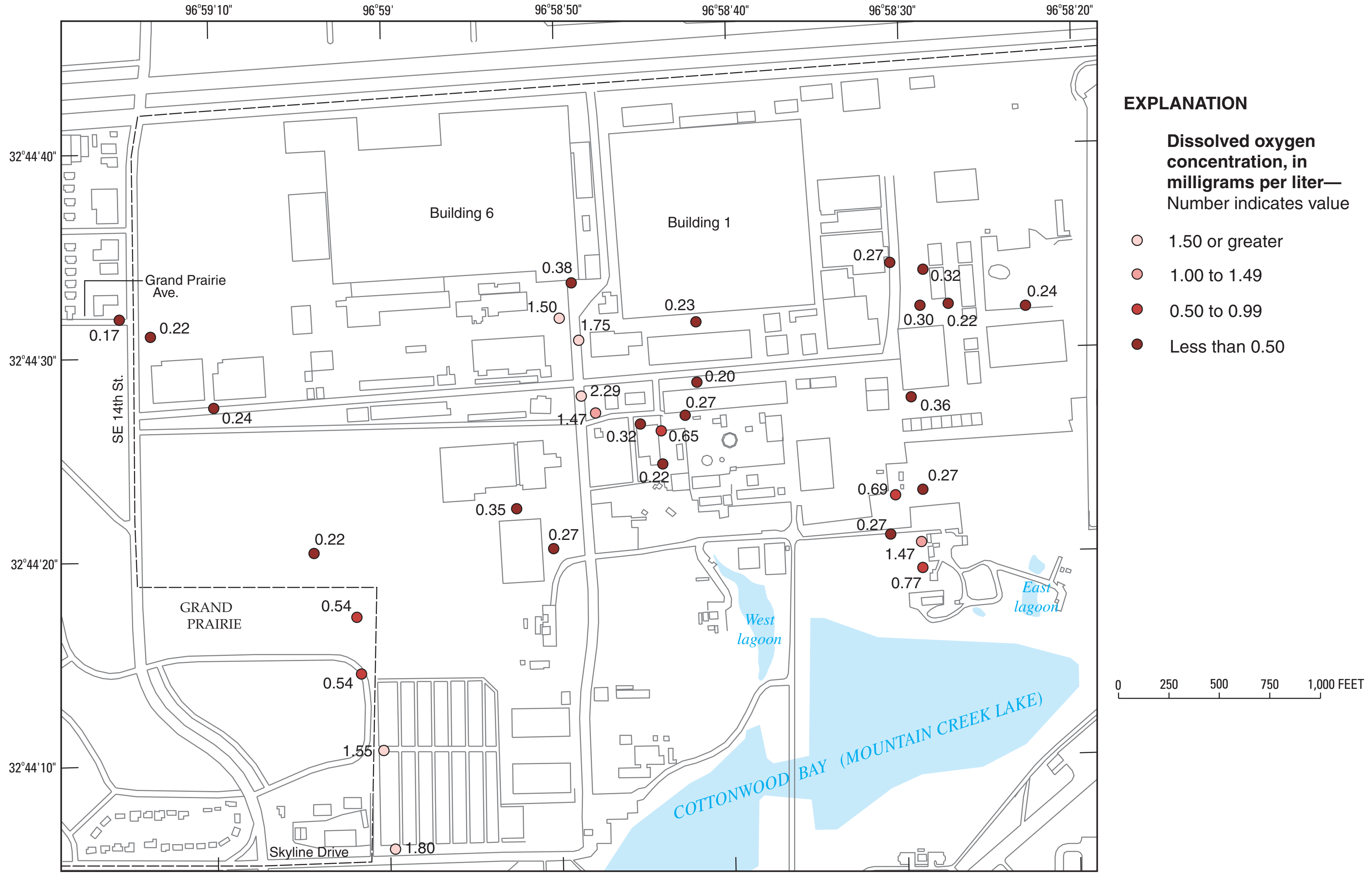


Figure 8. Dissolved oxygen concentrations from wells screened in the upper or in the upper and middle parts of the shallow alluvial deposits at the Naval Weapons Industrial Reserve Plant, Dallas, Texas, September 1997.

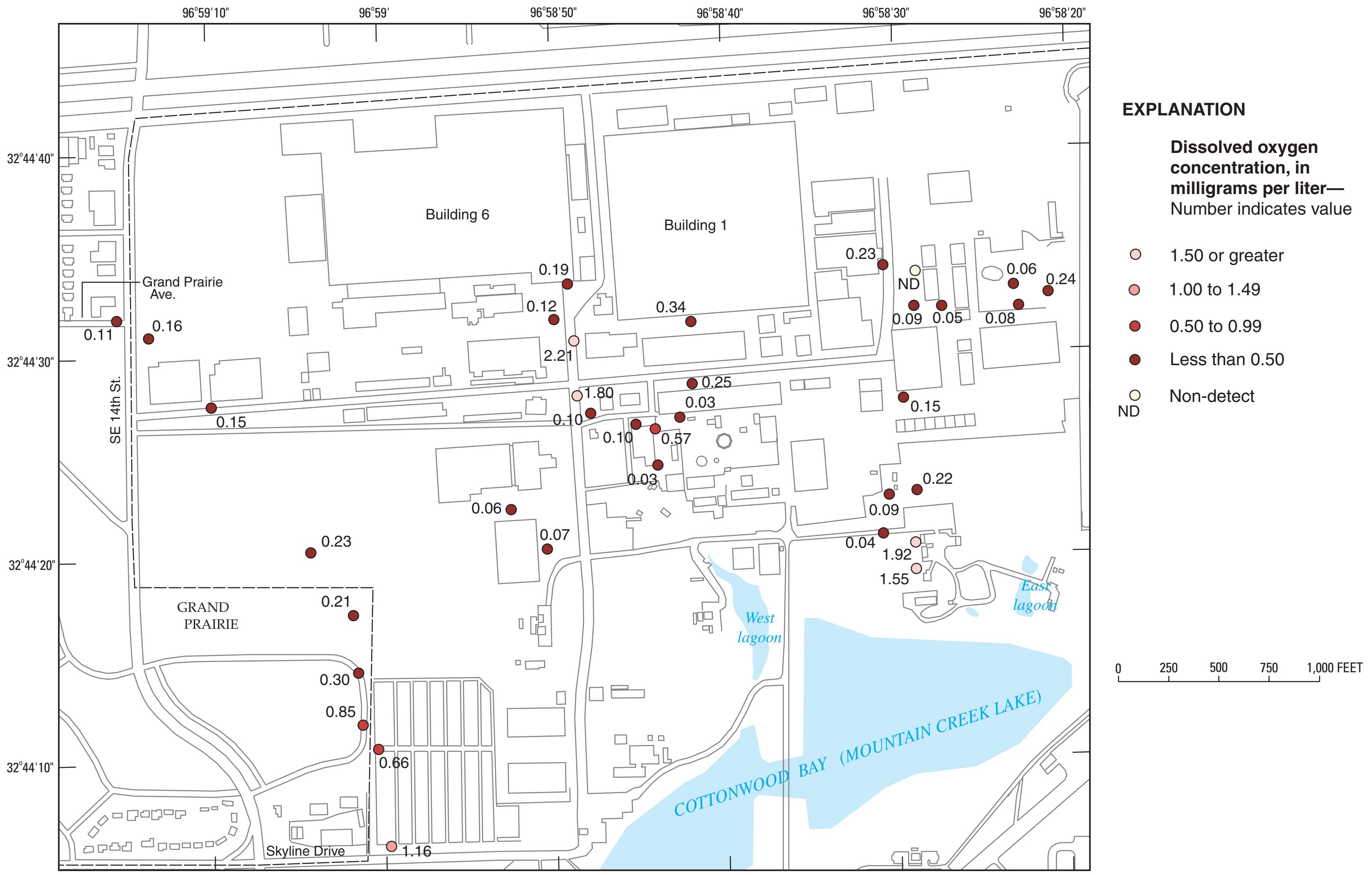


Figure 9. Dissolved oxygen concentrations from wells screened in the upper or in the upper and middle parts of the shallow alluvial deposits at the Naval Weapons Industrial Reserve Plant, Dallas, Texas, March 1998.

DWP–L2–5 (fig. 10). The three “L2” wells are located south of building 6, where nitrite (and nitrate) concentrations were larger than in most other areas of NWIRP. However, dissolved hydrogen concentrations indicate that the dominant redox process south of building 6 is ferric iron reduction.

Nitrate concentrations in uncontaminated shallow ground water generally are less than 2 mg/L (U.S. Geological Survey, 1999). Nitrate concentrations in wells DWP–L2–1, DWP–L2–16, and DWP–L2–5 were 25, 14.8, and 8.4 mg/L, respectively (appendix). The presence of nitrate at these relatively high concentrations, in addition to the larger DO concentrations, supports the possibility that an underground sewer pipe might be leaking south of building 6.

Ferrous Iron and Total Iron

Ferric iron is reduced to ferrous iron by the reaction

$$CH_2O + 4Fe(OH)_3 + 7H^+ \Rightarrow 4Fe^{+2} + HCO_3^- + 10H_2O. \quad (4)$$

Because of this process, an increase in ferrous iron concentration is expected where ferric iron reduction is occurring. Concentrations greater than about 1.00 mg/L indicate that iron reduction is probable (U.S. Environmental Protection Agency, 1993). The concentrations of ferrous iron in September 1997 and March 1998 (figs. 11, 12) indicate places where iron reduction probably is occurring, assuming that sulfide production from sulfate reduction is negligible.

Sulfate and Sulfide

Sulfate is reduced to hydrogen sulfide during sulfate reduction as follows:

$$2CH_2O + SO_4^{-2} \Rightarrow HCO_3^- + HS^- + CO_2 + H_2O. \quad (5)$$

Because of this process, an increase in sulfide is expected where sulfate reduction is occurring, assuming that locally, sulfide production exceeds iron reduction. The generally low concentrations of sulfide (figs. 13, 14) indicate that sulfate reduction is not a key process in the parts of the shallow alluvial deposits sampled.

Dissolved Hydrogen

Dissolved hydrogen concentrations (figs. 15, 16) indicate that ferric iron reduction is the most common redox process at the sampled wells. Dissolved hydrogen concentrations ranged from less than the method detection limit to more than 2,000 nM (table 4). Extremely large concentrations of hydrogen (greater than 50 nM) can be produced in newly installed wells, in wells pumped with direct-current-driven submersible pumps, and in wells with iron casing or screens (Chapelle and others, 1997). The relatively large hydrogen concentrations measured in this study are attributed to the installation of new wells. Excluding hydrogen concentrations greater than 50 nM, the median concentration of samples containing dissolved hydrogen was 0.53 nM for samples collected in September 1997 and 0.45 nM for samples collected in March 1998. These concentrations are typical indicators of ferric iron reduction (fig. 4).

Suarez and Rifai (1999) compiled a database of mean first-order decay rates for chlorinated solvents (table 5) from field and laboratory studies. From the table, the mean first-order decay rate associated with iron reduction for TCE is 0.003 day^{-1}. Using the general equation for first-order decay, $1n\ (0.5) = -kt_{1/2}$, where k is the decay rate, and $t_{1/2}$ is the half-life, a mean half-life of 231 days is computed for TCE. The computed mean half-life for DCE in iron reducing conditions is 347 days and for VC is 2.7 days. Decay constants were not computed for NWIRP, but it is expected that decay rates at NWIRP would be similar to the decay rates thus computed.

Total Organic Carbon

Analytical screening criteria were developed by USEPA as part of a weighted scoring method to indicate where reductive dechlorination might be likely to occur (U.S. Environmental Protection Agency, 1998). (See next section.) The criterion for TOC is that 20 mg/L is required for reductive dechlorination to proceed efficiently. TOC concentrations at NWIRP ranged from less than the method detection limit to 11.9 mg/L in samples collected in September 1997 (appendix). Results of VOC analyses from September 1997 samples showed very few wells with anthropogenic carbon compounds such as benzene, toluene, ethylbenzene, or xylene. The lack of a sufficient organic carbon source, whether naturally occurring or anthropogenic, can be a limiting factor for efficient reductive dechlorination (Suarez and Rifai, 1999).

Screening Results

The USEPA has developed a weighted scoring method to indicate sites where reductive dechlorination

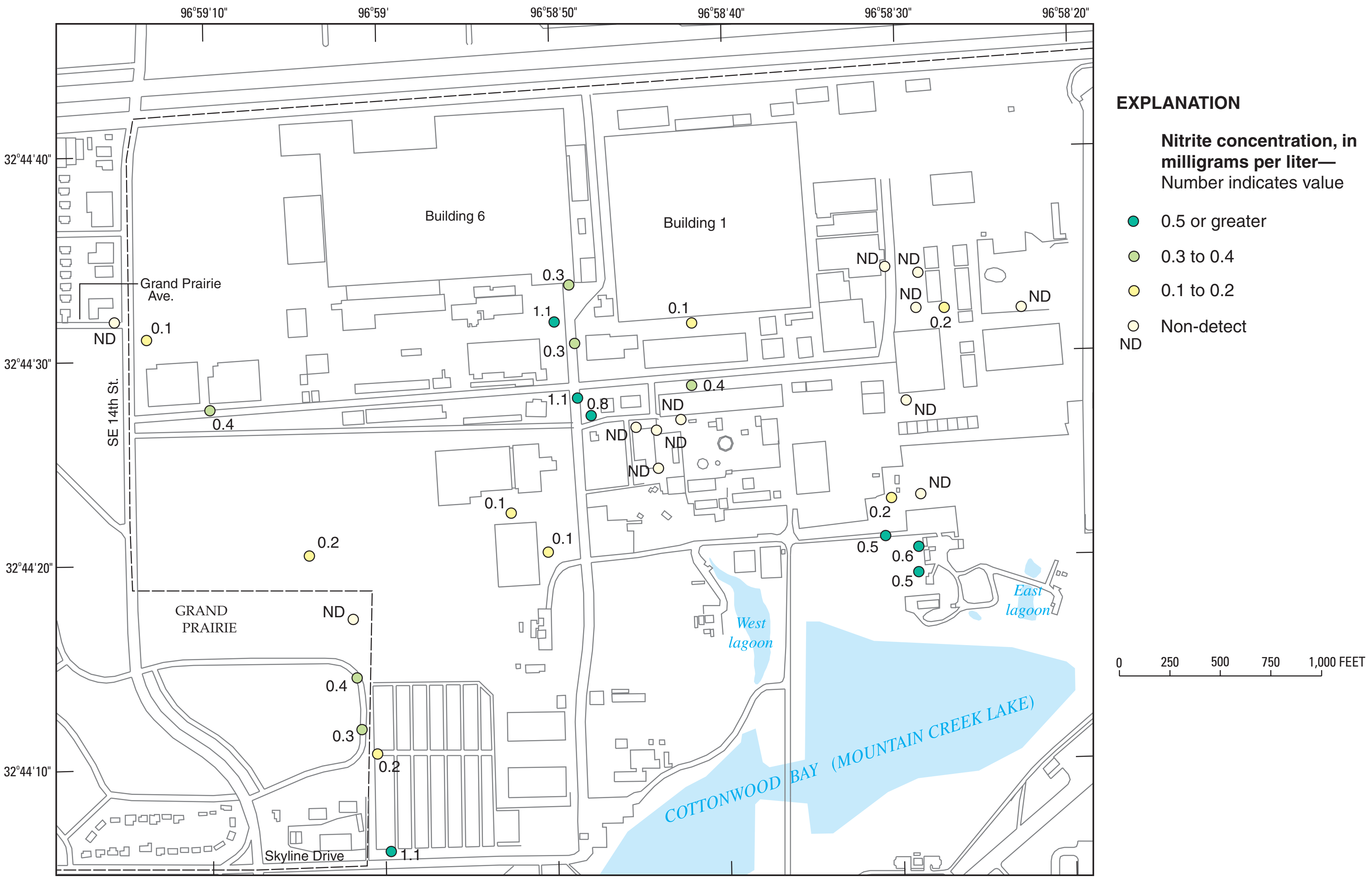


Figure 10. Nitrite concentrations from wells screened in the upper or in the upper and middle parts of the shallow alluvial deposits at the Naval Weapons Industrial Reserve Plant, Dallas, Texas, September 1997.

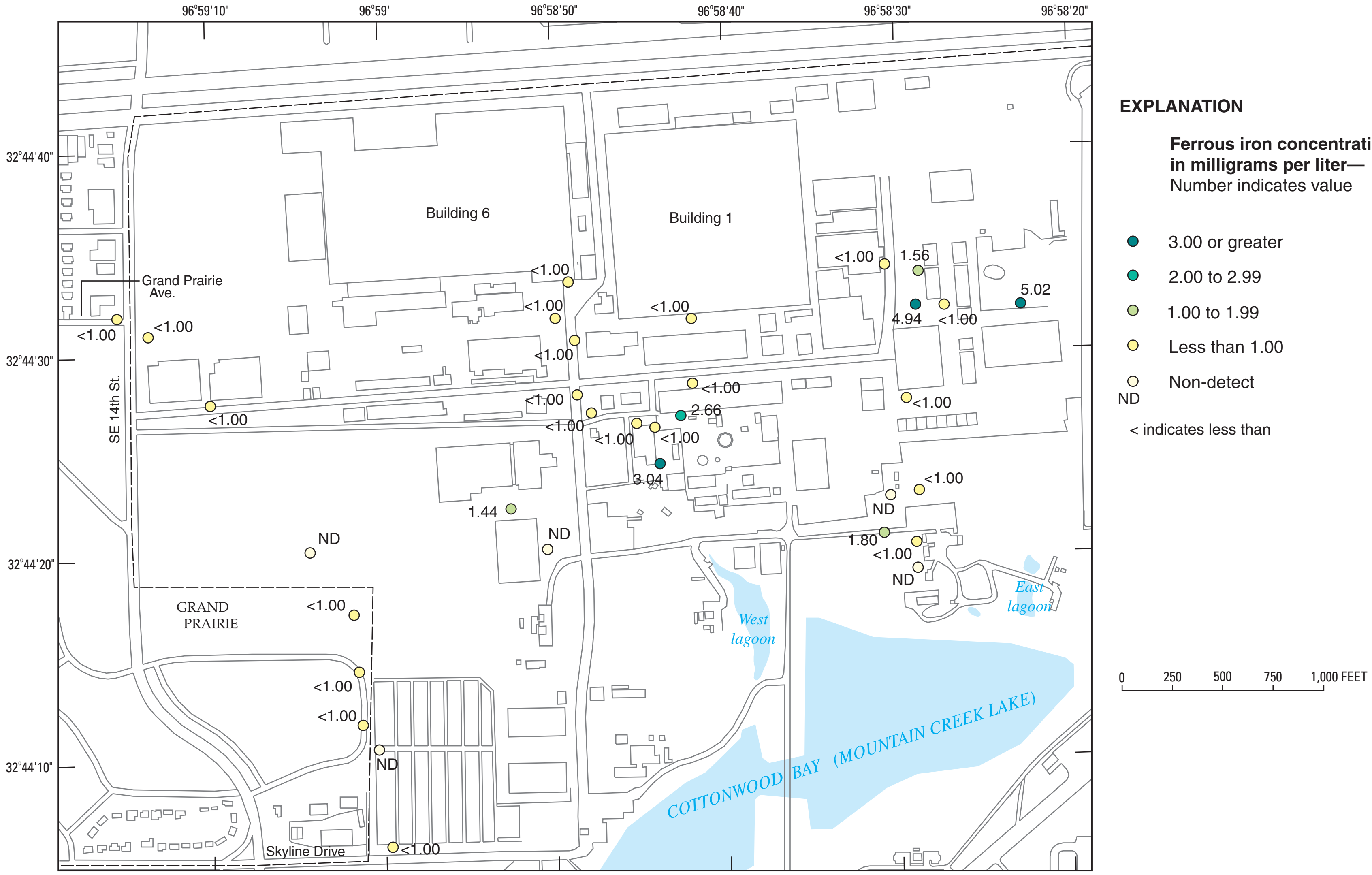


Figure 11. Ferrous iron concentrations from wells screened in the upper or in the upper and middle parts of the shallow alluvial deposits at the Naval Weapons Industrial Reserve Plant, Dallas, Texas, September 1997.

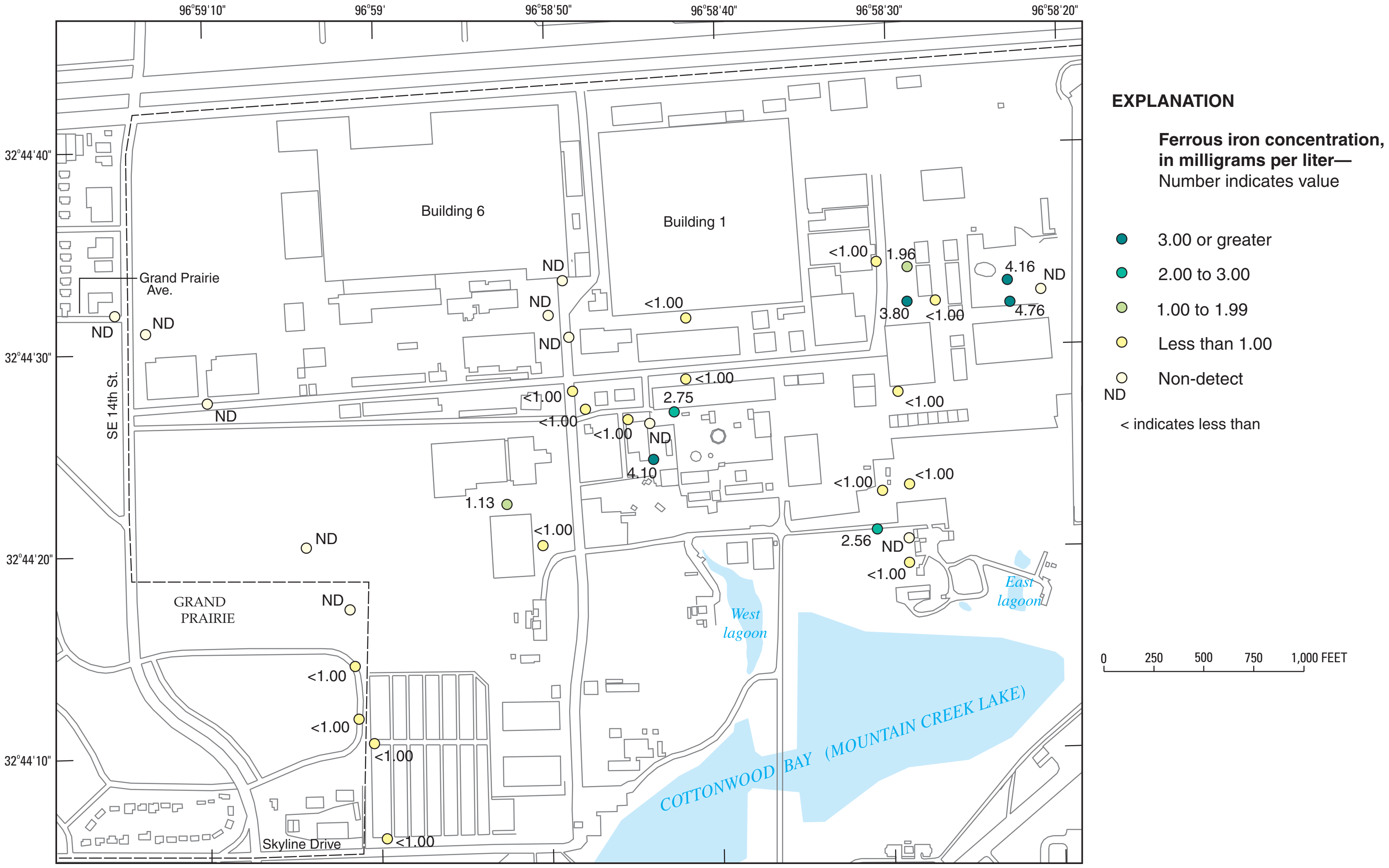


Figure 12. Ferrous iron concentrations from wells screened in the upper or in the upper and middle parts of the shallow alluvial deposits at the Naval Weapons Industrial Reserve Plant, Dallas, Texas, March 1998.

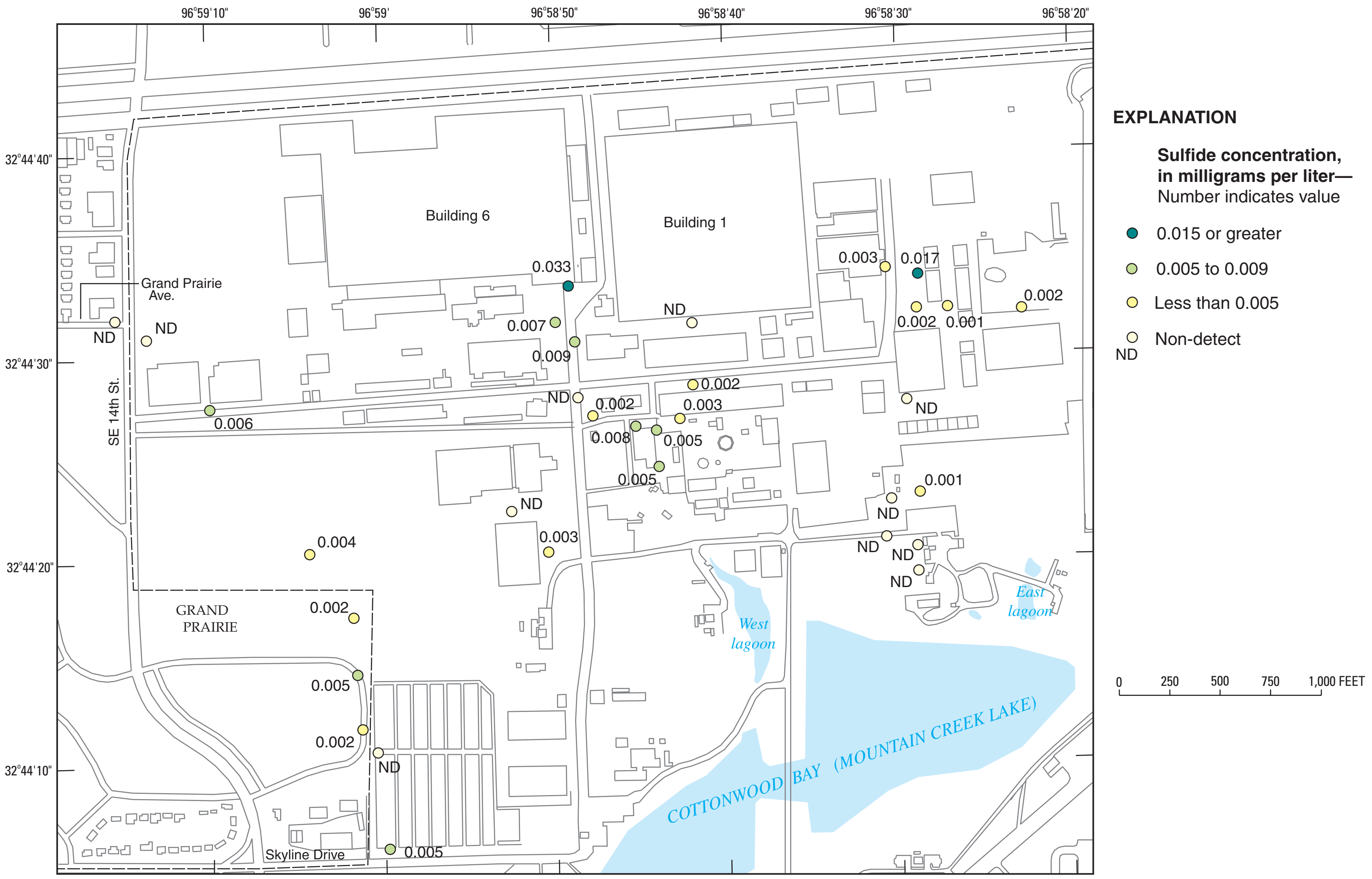


Figure 13. Sulfide concentrations from wells screened in the upper or in the upper and middle parts of the shallow alluvial deposits at the Naval Weapons Industrial Reserve Plant, Dallas, Texas, September 1997.

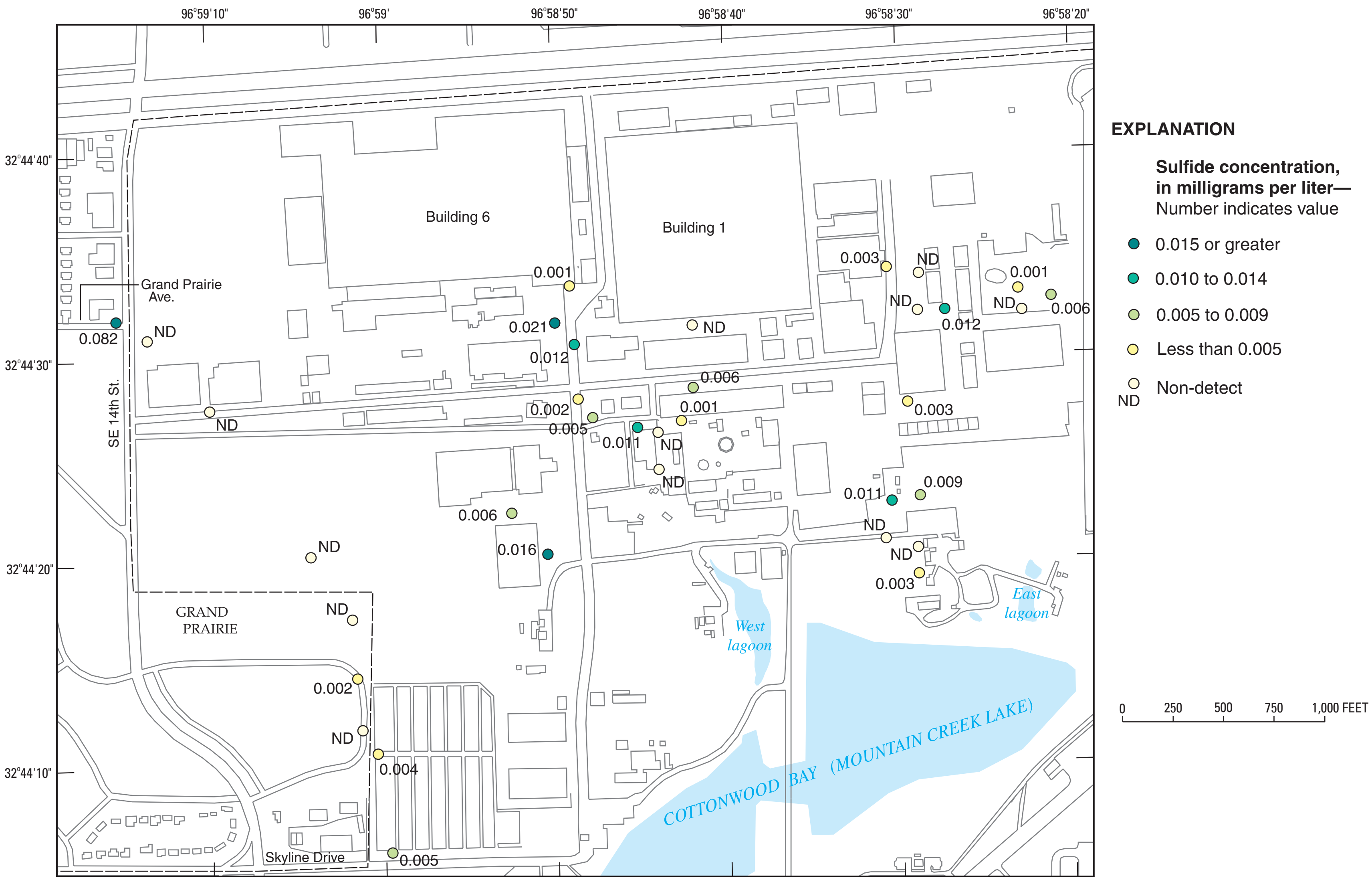


Figure 14. Sulfide concentrations from wells screened in the upper or in the upper and middle parts of the shallow alluvial deposits at the Naval Weapons Industrial Reserve Plant, Dallas, Texas, March 1998.

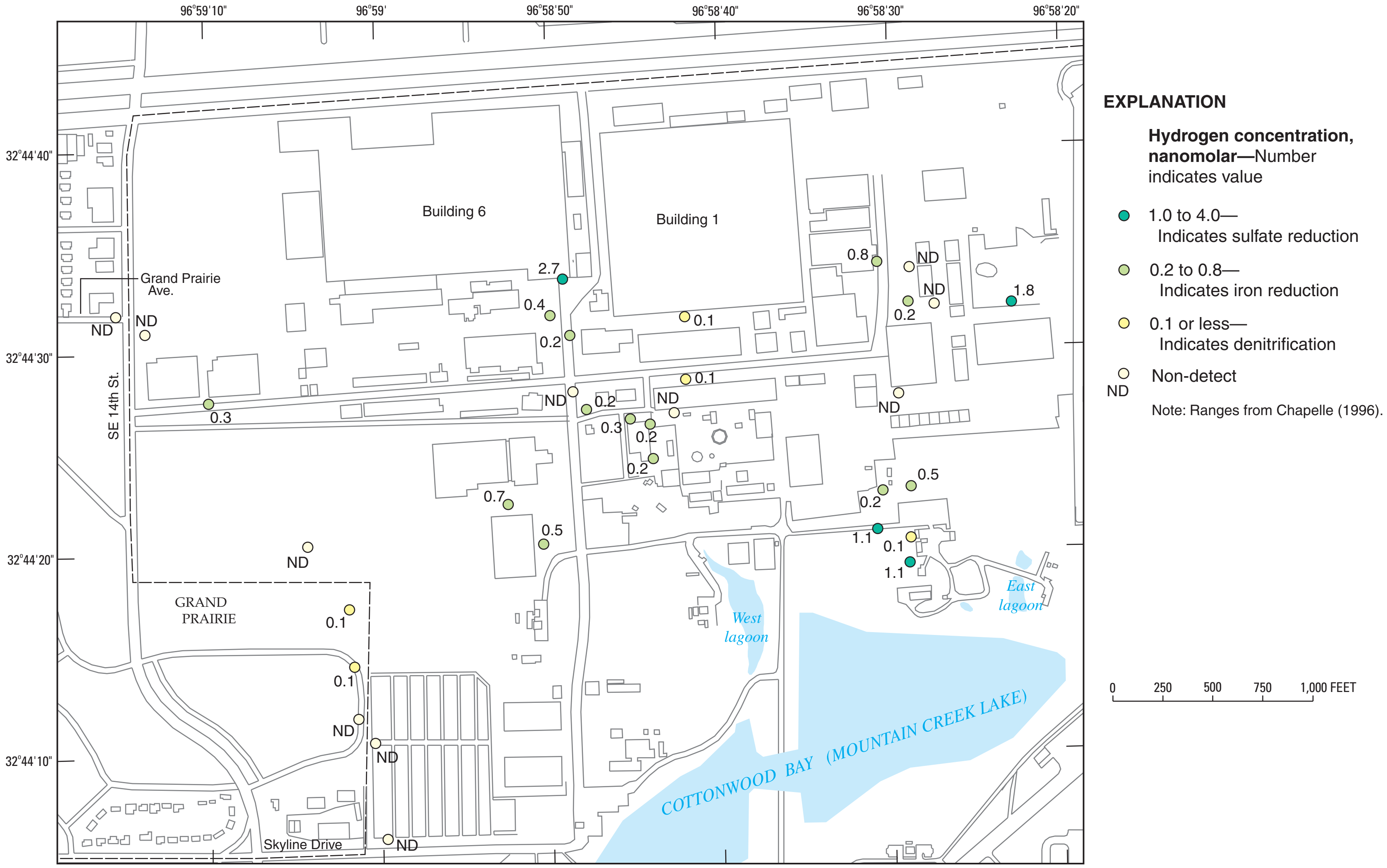
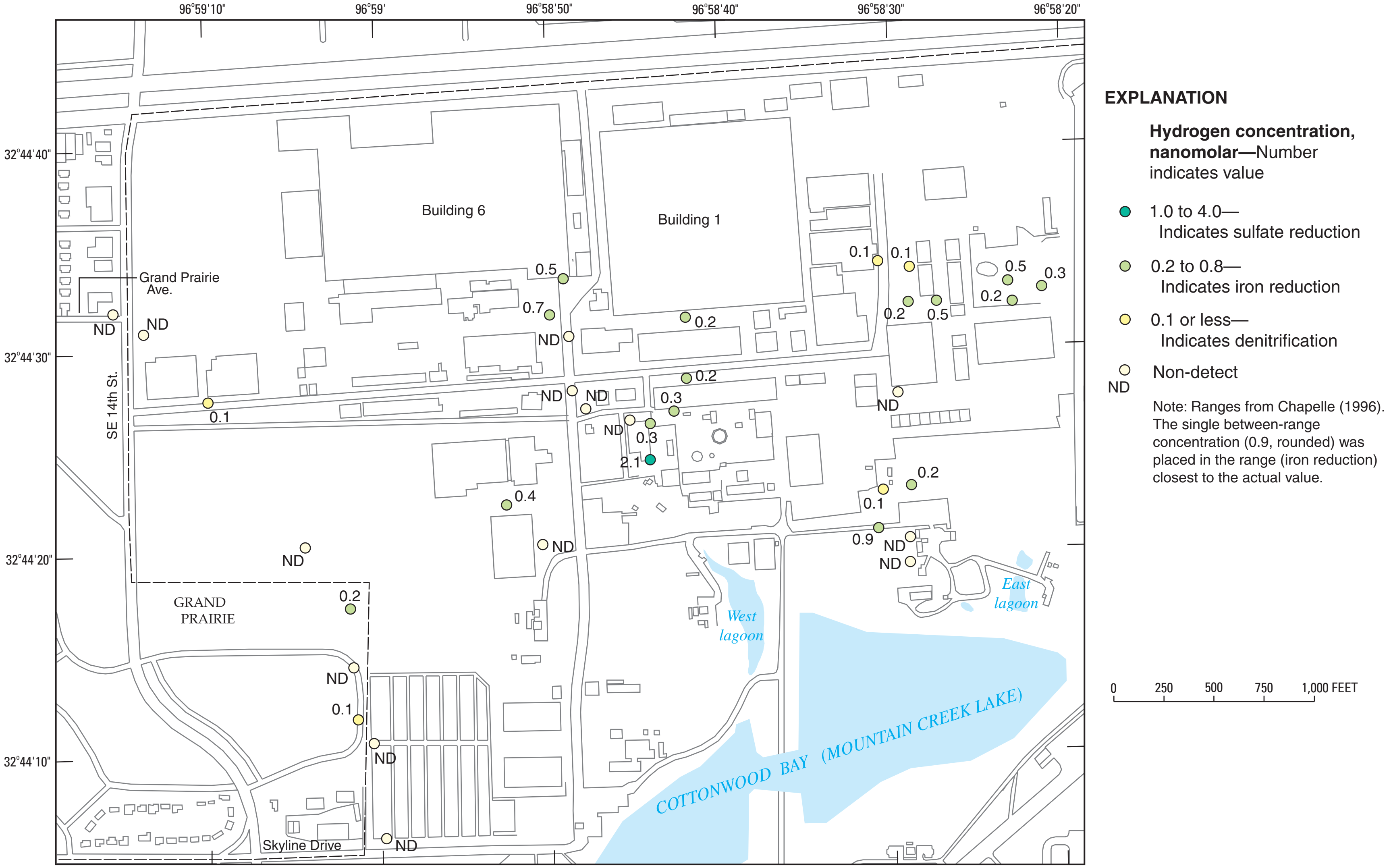


Figure 15. Dissolved hydrogen concentrations from wells screened in the upper or in the upper and middle parts of the shallow alluvial deposits and indicated oxidation-reduction processes at the Naval Weapons Industrial Reserve Plant, Dallas, Texas, September 1997.



Note: Ranges from Chapelle (1996). The single between-range concentration (0.9, rounded) was placed in the range (iron reduction) closest to the actual value.

Figure 16. Dissolved hydrogen concentrations from wells screened in the upper or in the upper and middle parts of the shallow alluvial deposits and indicated oxidation-reduction processes at the Naval Weapons Industrial Reserve Plant, Dallas, Texas, March 1998.

might be likely to occur (U.S. Environmental Protection Agency, 1998). Monitored natural attenuation (MNA) scores for sites (wells) are computed on the basis of concentrations of selected constituents. An MNA score of 0 to 5 of a possible 49 indicates inadequate evidence for anaerobic biodegradation of chlorinated solvents; a score of 6 to 14 indicates limited evidence for anaerobic biodegradation of chlorinated solvents; a score of 15 to 20 indicates adequate evidence for anaerobic biodegradation of chlorinated solvents; and a score greater than 20 indicates strong evidence for anaerobic biodegradation of chlorinated solvents. The work at NWIRP was done before the USEPA released its list of screening constituents; therefore not all the screening constituents were analyzed for this study. To score the ground-water samples collected from NWIRP in September 1997, a possible total score of 30 rather than 49 was used. Accordingly, the scoring also was modified—an MNA score of 0 to 3 indicated inadequate evidence for anaerobic biodegradation of chlorinated solvents; a score of 4 to 9 indicated limited evidence for anaerobic biodegradation of chlorinated solvents; a score of 10 to 12 indicated adequate evidence for anaerobic biodegradation of chlorinated solvents; and a score greater than 12 indicated strong evidence for anaerobic biodegradation of chlorinated solvents. The MNA score for each well is listed in table 3. Six wells had scores greater than 12. In general, scores were highest for samples collected on the northeast side of the facility, although three wells in the central part of the facility, DWP–5–12, DWP–S1–10, and DWP–S1–4 had scores greater than 12.

SUMMARY

Concentrations of TCE in ground water at NWIRP indicate three source areas of chlorinated solvents—building 1, building 6, and an off-site source west of the facility. The presence of *cis*-DCE and VC, products of reductive dechlorination of TCE that were not used at the facility, south and southwest of the source areas are evidence that reductive dechlorination is occurring.

The efficiency of reductive dechlorination in ground water is controlled by redox processes. The most common redox processes in ground water are the reduction of oxygen, nitrate (denitrification), ferric iron, sulfate, and carbon dioxide (methanogenesis). Concentrations of reduced species (for example, nitrite, ferrous iron) at a particular site can indicate which redox process is dominant, but sometimes concentrations of reduced species are not definitive. In such cases, concentrations of dissolved hydrogen in specific ranges can indicate which redox process is dominant. In places south of the source areas, DO concentrations indicated that reduction of oxygen could be the dominant process, particularly south of building 6; but elevated DO concentrations south of building 6 might be caused by a leaking water or sewer pipe. The nitrite data indicate that denitrification is occurring in places; however dissolved hydrogen concentrations indicate that iron reduction is the dominant process south of building 6. The distributions of ferrous iron indicate that iron reduction is occurring in places south-southwest of buildings 6 and 1; dissolved hydrogen concentrations generally support the interpretation that iron reduction is the dominant process in those places. The generally low concentrations of sulfide indicate that sulfate reduction is not a key process in most sampled areas, an interpretation that is supported by dissolved hydrogen concentrations.

Dissolved hydrogen concentrations at sampled wells were most frequently in the range that indicated ferric iron reduction is the primary redox process. Applying mean first-order decay rates for TCE, *cis*-DCE, and VC in iron-reducing conditions from a recent study resulted in mean half-lives for TCE, *cis*-DCE, and VC of 231, 347, and 2.67 days, respectively. Decay rates were not computed for NWIRP, but it is expected that decay rates, and thus half-lives, at NWIRP would be similar to those computed.

Small concentrations of TOC indicate the lack of an organic carbon source, which could be a limiting factor for efficient reductive dechlorination at NWIRP.

The USEPA has developed a weighted scoring method to indicate sites where reductive dechlorination might be likely to occur. At NWIRP, a score greater than 12 indicated strong evidence for anaerobic biodegradation of chlorinated solvents. Scores greater than 12 were computed for six sites. In general, scores were highest for samples collected on the northeast side of the facility, although three sites in the central part of NWIRP had scores greater than 12.

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Table 1. Well information and sampling dates for wells sampled at the Naval Weapons Industrial Reserve Plant, Dallas, Texas

[“Both” indicates that the screen penetrates both the upper and middle parts of the shallow alluvial aquifer]

Well number (fig. 1)	Date sampled		Well depth (feet below land surface)	Screened interval (feet below and surface)	Part of shallow alluvial aquifer in which well is screened	Well altitude (feet above NGVD of 1929)
	USGS	EnSafe/ Allen & Hoshall				
DWP–10–1	9/97 and 3/98	9/97	24	8–23	Both	486.6
DWP–10–2	3/98	--	29	13–28	Both	486
DWP–10–6	3/98	--	24	13–23	Upper	490
DWP–10–DW1	3/98	9/97	59	50–55	Lower	486
DWP–10–DW4	9/97 and 3/98	9/97	64	59–64	Lower	490.1
DWP–10–DW6	3/98	9/97	54	34–54	Middle & lower	492
DWP–1–13	9/97 and 3/98	9/97	19	3–18	Middle	471.4
DWP–128–1	9/97 and 3/98	9/97	25	4.5–24.5	Upper	484.9
DWP–1–9	9/97 and 3/98	9/97	29	13–28	Lower	464.5
DWP–4–10	9/97 and 3/98	9/97	14	3–13	Middle	458.4
DWP–4–14	9/97 and 3/98	9/97	22	10–20	Lower	461.5
DWP–4–2	9/97 and 3/98	--	22	11–21	Both	479.7
DWP–4–4	9/97 and 3/98	--	31	10–30	Both	483.1
DWP–4–5	9/97 and 3/98	9/97	29	13–28	Both	490.2
DWP–4–8	9/97 and 3/98	9/97	33	17–32	Both	489.6
DWP–4–9	9/97 and 3/98	9/97	29	13–28	Both	476.6
DWP–5–12	9/97 and 3/98	--	32	16–31	Upper	488.7
DWP–5–13	9/97 and 3/98	9/97	29	13–28	Both	485.3
DWP–7–6	9/97 and 3/98	--	32	15–25	Middle	476.9
DWP–BG–10	9/97 and 3/98	9/97	21	5–20	Both	486.8
DWP–BG–4	9/97 and 3/98	9/97	34	18–33	Middle	501.7
DWP–BG–4–3	9/97 and 3/98	9/97	28	18–28	Both	503.2
DWP–BG–4–6	9/97 and 3/98	9/97	30	15–30	Both	500.2
DWP–BG-6	9/97 and 3/98	--	39	23–38	Lower	470.8
DWP–BG–7	9/97 and 3/98	9/97	29	13–28	Upper	499.6
DWP–BG–8	9/97 and 3/98	--	19	3.5–18.5	Both	478.9
DWP–DBG–3	9/97 and 3/98	9/97	47	38–43	Lower	479
DWP–L1–5	9/97 and 3/98	9/97	34	18–33	Middle	488.7
DWP–L2–1	9/97 and 3/98	9/97	34	18–33	Upper	496.6
DWP–L2–16	9/97 and 3/98	9/97	29	13–28	Upper	494.6
DWP–L2–4	9/97 and 3/98	9/97	29	13–28	Upper	494.6
DWP–L2–5	9/97 and 3/98	--	27	11–26	Upper	494.6
DWP–L2–8	9/97 and 3/98	9/97	27	11–26	Upper	494.9
DWP–L2–DW1	9/97 and 3/98	9/97	60.5	55–60	Lower	495
DWP–L2–DW2	9/97 and 3/98	9/97	48	42–47	Middle	495

Table 1. Well information and sampling dates for wells sampled at the Naval Weapons Industrial Reserve Plant, Dallas, Texas—Continued

Well number (fig. 1)	Date sampled		Well depth (feet below land surface)	Screened interval (feet below and surface)	Part of shallow alluvial aquifer in which well is screened	Well altitude (feet above NGVD of 1929)
	USGS	EnSafe/ Allen & Hoshall				
DWP–OFF–10	9/97 and 3/98	9/97	29	13–28	Upper	495.3
DWP–OFF–11	9/97 and 3/98	9/97	24	13–23	Both	493.9
DWP–OFF–12	3/98	9/97	24	16–23.5	Lower	458
DWP–OFF–14	3/98	9/97	20	13–18	Lower	459
DWP–OFF–5	9/97 and 3/98	9/97	34	18–33	Both	501.8
DWP–S1–10	9/97 and 3/98	9/97	29	13–28	Middle	474.8
DWP–S1–11	9/97 and 3/98	--	39	23–38	Middle	486.5
DWP–S1–17	9/97 and 3/98	9/97	29	21–26	Upper	488.5
DWP–S1–18	9/97 and 3/98	9/97	27	11–26	Upper	487.6
DWP–S1–4	9/97 and 3/98	9/97	32	13–31	Upper	495.4
DWP–S1–5	9/97 and 3/98	--	26	10–25	Upper	485.0
DWP–S1–7	9/97 and 3/98	9/97	30	14–29	Upper	493.2
DWP–S1–DW1	9/97 and 3/98	9/97	62.5	52–62	Lower	489
DWP–S1–DW2	9/97 and 3/98	--	48	38–45.5	Middle	488
DWP–S2–11	9/97 and 3/98	9/97	27	11–26	Upper	491.2
DWP–S2–16	9/97 and 3/98	9/97	29	13–28	Upper	492
DWP–S2–18	9/97 and 3/98	9/97	27	11–26	Both	490
DWP–S2–2	9/97 and 3/98	9/97	35	20–35	Upper	494.7
DWP–S2–5	9/97 and 3/98	9/97	33	17–32	Both	491.5
DWP–S2–DW1	9/97 and 3/98	9/97	71.5	62.5–67.5	Lower	492
DWP–S2–DW2	9/97 and 3/98	9/97	57	41–56	Middle	492
DWP–S5–10	9/97 and 3/98	9/97	32	15–30	Upper	497.8

Table 2. Selected constituents, methods, and procedures used to evaluate oxidation-reduction processes in ground water at the Naval Weapons Industrial Reserve Plant, Dallas, Texas

[GCMS, gas chromatography/mass spectroscopy]

Constituent	Method	Procedure
Volatile organic compounds	[1]8260 and field chromatography	GCMS (laboratory) and gas chromatography (field)
Dissolved oxygen	Indigo carmine[2]	Colorimetric analysis (field)
Nitrate and nitrate + nitrite	[3]300.0 and [4]353.2	Ion chromatography (laboratory)
Ferrous and total iron	HACH[5] methods 255 and 265	Colorimetric analysis (field)
Sulfide	HACH[5] method 690	Colorimetric analysis (field)
Dissolved hydrogen	Bubble strip[6]	Reduction gas analysis (field)
Total organic carbon	[7]9060	Wet oxidation (laboratory)

[1] U.S. Environmental Protection Agency, 1999.

[2] Gilbert and others, 1982.

[3] U.S. Environmental Protection Agency, 1993.

[4] U.S. Environmental Protection Agency, 1983.

[5] HACH Co., 1989.

[6] Chapelle, 1996.

[7] U.S. Environmental Protection Agency, 1999.

Table 3. Chemical results for selected volatile organic compounds from wells sampled at the Naval Weapons Industrial Reserve Plant, Dallas, Texas

[September 1997 data collected by EnSafe and analyzed by laboratory gas chromatograph/mass spectrometer; March 1998 data collected by USGS and analyzed by portable field gas chromatograph. µg/L, micrograms per liter; MNA, monitored natural attenuation; <, less than; ND, not detected; >, greater than; --, no data]

Well number	Trichloroethene (µg/L)		*cis*-1,2-Dichloroethene (µg/L)		*trans*-1,2-Dichloroethene (µg/L)		Vinyl chloride (µg/L)		Ratio of trichloroethene to *cis*-1,2-dichloroethene		MNA score
	9/97	3/98	9/97	3/98	9/97	3/98	9/97	3/98	9/97	3/98	9/97
DWP–10–1	36	[1]2	<10	[1]6	<10	ND	<10	[1]2	>3.6	0.3	14
DWP–10–2	--	50	--	54	--	ND	--	94	--	.9	--
DWP–10–6	--	450	--	[1]4	--	ND	--	ND	--	112.5	--
DWP–10–DW1	[2]52,000	13,000	[2]960	7,900	[1]9	[1]3	[1]46	13	54.2	1.6	--
DWP–10–DW4	[2]3,000	27	[2]680	[1]8	[1]11	ND	[1]27	ND	4.4	3.4	10
DWP–10–DW6	15,000	5,000	[1]320	47	<1,000	[1]2	<1,000	ND	46.9	106.4	--
DWP–1–13	[2]180	220	[2]350	300	13	10	[1]20	[1]3	.5	.7	10
DWP–128–1	[2]940	29	[2]200	12	[1]2	[1]1	63	[1]2	4.7	2.4	11
DWP–1–9	260	350	180	350	5	5	32	7	1.4	1.0	10
DWP–4–10	ND	5	130	150	[1].8	[1]1	61	33	0	0	10
DWP–4–14	180	110	240	140	[1]8	[1]4	80	7	.8	.8	10
DWP–4–2	--	250	--	160	--	10	--	ND	--	1.6	--
DWP–4–4	--	16	--	1,900	--	8	--	84	--	0	12
DWP–4–5	3,100	2,200	[1]280	230	<500	15	<500	[1]4	11.1	9.6	3
DWP–4–8	510	310	540	350	[1]29	13	<50	[1]1	.9	.9	6
DWP–4–9	420	310	200	130	[1]23	10	<50	ND	2.1	2.4	5
DWP–5–12	--	27	--	5	--	ND	--	[1]1	--	5.4	14
DWP–5–13	[2]510	660	[1]86	95	[1]9	8	[1]7	[1]1	5.9	6.9	12
DWP–7–6	--	260	--	78	--	4	--	[1]1	--	3.3	4
DWP–BG–10	120	170	<10	ND	<10	ND	<10	ND	>12.0	>170.0	--
DWP–BG–4	680	640	63	55	<50	ND	<50	ND	10.8	11.6	8
DWP–BG–4–3	110	66	11	6	<10	ND	<10	ND	10.0	11.0	8
DWP–BG–4–6	[1]9	20	<10	ND	<10	ND	<10	ND	>.9	>20.0	4
DWP-BG-6	--	33	--	[1]2	--	ND	--	ND	--	16.5	4
DWP–BG–7	590	450	28	36	<50	[1]3	<50	ND	21.1	12.5	3
DWP–BG–8	--	9	--	ND	--	ND	--	ND	--	>9.0	1
DWP–DBG–3	--	7	--	[1]1	--	ND	--	ND	--	7.0	12
DWP–L1–5	ND	390	<10	280	<10	ND	<10	ND	0	1.4	11
DWP–L2–1	3,000	1,400	300	220	<200	ND	<200	ND	10.0	6.4	3
DWP–L2–16	[2]1,200	290	[2]220	170	1	ND	<10	ND	5.5	1.7	3
DWP–L2–4	27,000	12,000	[1]310	230	<2,000	2	<2,000	ND	87.1	52.2	3
DWP–L2–5	--	450	--	6	--	ND	--	ND	--	75.0	4

Footnotes at end of table.

Table 3. Chemical results for selected volatile organic compounds from wells sampled at the Naval Weapons Industrial Reserve Plant, Dallas, Texas—Continued

Well number	Trichloro-ethene (μg/L)		*cis*-1,2-Dichloro-ethene (μg/L)		*trans*-1,2-Dichloro-ethene (μg/L)		Vinyl chloride (μg/L)		Ratio of trichloroethene to *cis*-1,2-dichloroethene		MNA score
	9/97	3/98	9/97	3/98	9/97	3/98	9/97	3/98	9/97	3/98	9/97
DWP–L2–8	5,600	3,200	65	90	<500	ND	<500	ND	86.2	35.6	11
DWP–L2–DW1	200	350	[1]3	25	<20	1	<20	ND	66.7	14.0	3
DWP–L2–DW2	4,500	2,200	[1]25	620	<250	ND	<250	ND	180.0	3.5	8
DWP–OFF–10	[2]420	620	[1]1	[1]4	<10	ND	<10	ND	--	155.0	5
DWP–OFF–11	[2]270	340	<10	[1]1	<10	ND	<10	ND	>27.0	340.0	--
DWP–OFF–12	36	58	22	15	[1]1	[1]1	<10	ND	1.6	3.9	--
DWP–OFF–14	16	23	14	11	[1]1	ND	[1]2	ND	1.1	2.1	--
DWP–OFF–5	13,000	6,800	4,500	2,700	<1,000	8	<1,000	24	2.9	2.5	8
DWP–S1–10	[2]14,000	5,600	[2]970	520	100	33	170	10	14.4	10.8	13
DWP–S1–11	--	700	--	17	--	[1]1	--	ND	--	41.2	9
DWP–S1–17	[1]2	27	<10	16	<10	[1]3	<10	10	0	1.7	9
DWP–S1–18	[2]4,600	2,400	[2]430	320	10	3	66	[1]3	10.7	7.5	10
DWP–S1–4	[2]440	290	23	15	<10	ND	27	[1]1	19.1	19.3	14
DWP–S1–5	--	8	--	3,200	--	410	--	ND	--	0	--
DWP–S1–7	23	45	<10	2	<10	ND	<10	ND	>2.3	22.5	6
DWP–S1–DW1	[1].5	66	<10	[1]2	<10	ND	<10	ND	0	33.0	6
DWP–S1–DW2	<10	9	<10	ND	<10	ND	<10	ND	1.0	>9.0	6
DWP–S2–11	[1]400	150	[2]2,700	1,100	64	14	[1]86	[1]3	.1	.1	12
DWP–S2–16	[2]3,400	4,300	[2]9,300	1,100	[1]47	37	[2]420	180	.4	3.9	16
DWP–S2–18	[2]720	1,030	130	134	[1]5	[1]3	[1]7	[1]2	5.5	7.7	10
DWP–S2–2	13	46	180	150	26	19	[1]3	2	.1	.3	10
DWP–S2–5	<10	ND	[2]1,500	540	[1]36	7	[2]4,400	170	0	0	16
DWP–S2–DW1	[1]7	18	[1]4	21	<10	ND	<10	550	1.8	.9	11
DWP–S2–DW2	[1]430	17	[1]41	270	<10	ND	<10	[1]2	10.5	.1	5
DWP–S5–10	240	210	<10	[1]1	<10	ND	<10	ND	>24.0	210.0	4

[1] Estimated.

[2] Sample diluted during analysis.

Table 4. Selected field and laboratory data from wells sampled at the Naval Weapons Industrial Reserve Plant, Dallas, Texas

[Nitrite data from laboratory, all other data analyzed from unfiltered samples in the field. mg/L, milligrams per liter; nM, nanomolar; ND, not detected; --, no data]

Well number	Dissolved oxygen (mg/L)		Nitrite (mg/L)		Ferrous iron (mg/L)		Sulfide (mg/L)		Dissolved hydrogen (nM)	
	9/97	3/98	9/97	3/98	9/97	3/98	9/97	3/98	9/97	3/98
DWP–10–1	0.24	0.08	ND	--	5.02	[1]4.76	0.002	ND	1.8	0.2
DWP–10–2	--	.06	--	--	--	[1]4.16	--	.001	--	.5
DWP–10–6	--	.24	--	--	--	ND	--	.006	--	.3
DWP–10–DW1	--	1.28	--	--	--	.90	--	ND	--	.6
DWP–10–DW4	.19	.14	ND	--	.84	1.22	.003	.007	ND	.3
DWP–10–DW6	--	.06	--	--	--	.10	--	.008	--	ND
DWP–1–13	.14	[2].04	ND	--	[3].02	ND	.001	.002	ND	.1
DWP–128–1	.22	[2].03	ND	--	[1]3.04	[1]4.10	.005	ND	.2	2.1
DWP–1–9	.20	.45	.6	--	[3].10	ND	.002	.001	ND	.2
DWP–4–10	.44	[2].04	ND	--	.14	.02	ND	.001	.4	.2
DWP–4–14	.27	.13	.2	--	ND	ND	ND	ND	.2	ND
DWP–4–2	1.47	1.92	.6	--	.01	ND	ND	ND	.1	ND
DWP–4–4	.27	[2].04	.5	--	1.8	2.56	ND	ND	1.1	.9
DWP–4–5	.69	.09	.2	--	ND	.05	ND	.011	.2	.1
DWP–4–8	.27	.22	ND	--	.04	.02	.001	.009	.5	.2
DWP–4–9	.77	1.55	.5	--	ND	.04	ND	.003	1.1	ND
DWP–5–12	.35	.06	.1	--	1.44	1.13	ND	.006	.7	.4
DWP–5–13	.27	.07	.1	--	ND	.06	.003	.016	.5	ND
DWP–7–6	.20	.34	.4	--	[3].10	ND	.003	.006	ND	.3
DWP–BG–10	1.55	.66	.2	--	ND	.04	ND	.004	ND	ND
DWP–BG–4	.15	.78	.2	--	.02	ND	.001	ND	ND	ND
DWP–BG–4–3	.22	.16	.1	--	.03	ND	ND	ND	ND	ND
DWP–BG–4–6	.24	.15	.4	--	[3].09	ND	.006	ND	.3	.1
DWP–BG-6	.32	.16	ND	--	.01	ND	ND	ND	ND	.1
DWP–BG–7	.54	.21	ND	--	.02	ND	.002	ND	.1	.2
DWP–BG–8	1.8	1.16	1.1	--	.05	.02	.005	.005	ND	ND
DWP–DBG–3	.19	[2].02	.8	--	1.78	1.18	.014	ND	1.3	1.8
DWP–L1–5	.32	.15	.3	--	.75	[1]1.16	.007	.004	.5	1.7
DWP–L2–1	2.29	1.80	1.1	--	[3].37	.02	ND	.002	ND	ND
DWP–L2–16	1.47	.10	.8	--	[3].06	.04	.002	.005	.2	ND
DWP–L2–4	1.75	2.21	.3	--	[3].19	ND	.009	.012	.2	ND
DWP–L2–5	1.50	.12	1.1	--	[3].16	ND	.007	.021	.4	.7

Footnotes at end of table.

Table 4. Selected field and laboratory data from wells sampled at the Naval Weapons Industrial Reserve Plant, Dallas, Texas—Continued

Well number	Dissolved oxygen (mg/L)		Nitrite (mg/L)		Ferrous iron (mg/L)		Sulfide (mg/L)		Dissolved hydrogen (nM)	
	9/97	3/98	9/97	3/98	9/97	3/98	9/97	3/98	9/97	3/98
DWP–L2–8	0.38	0.19	0.3	--	0.03	ND	0.033	0.001	2.7	0.5
DWP–L2–DW1	1.24	.16	.3	--	[3].13	.03	.002	ND	.1	2.4
DWP–L2–DW2	.54	.26	.4	--	.12	.53	.001	.055	7.3	.3
DWP–OFF–10	.54	.30	.4	--	[3].10	.02	.005	.002	.1	ND
DWP–OFF–11	--	.85	.3	--	[3].14	.02	.002	ND	ND	.1
DWP–OFF–12	--	1.67	--	--	--	.06	--	.001	--	.7
DWP–OFF–14	--	.24	--	--	--	.08	--	ND	--	1
DWP–OFF–5	.17	.11	ND	--	.01	ND	ND	.082	ND	ND
DWP–S1–10	.27	.13	.4	--	[3].12	.02	.004	.003	.15	1.0
DWP–S1–11	.22	.22	.4	--	[3].17	ND	.012	.012	1.9	.5
DWP–S1–17	.27	[2].03	ND	--	2.66	2.75	.003	.001	ND	.3
DWP–S1–18	.32	.10	ND	--	[3].15	.03	.008	.011	.3	ND
DWP–S1–4	.2	.25	.4	--	.01	.05	.002	.006	.14	.2
DWP–S1–5	.65	.57	ND	--	[3].12	ND	.005	ND	.2	.3
DWP–S1–7	.23	.34	.1	--	[3].03	.01	ND	ND	.1	.2
DWP–S1–DW1	.32	.06	ND	--	.86	.88	.021	ND	2.0	.2
DWP–S1–DW2	.32	.05	ND	--	ND	.03	ND	.021	[4]670	[4]2,100
DWP–S2–11	.36	.15	ND	--	.16	.02	ND	.003	ND	ND
DWP–S2–16	.32	ND	ND	--	1.56	1.96	.017	ND	ND	.1
DWP–S2–18	.22	.05	.2	--	.01	.03	.001	.012	ND	.5
DWP–S2–2	.27	.23	ND	--	.31	.16	.003	.003	.8	.1
DWP–S2–5	.3	.09	ND	--	[1]4.94	[1]3.80	.002	ND	.2	.2
DWP–S2–DW1	.54	[2].04	ND	--	2.02	1.15	.024	ND	[4]290	.9
DWP–S2–DW2	1.14	.20	ND	--	.37	1.72	.006	.003	.6	2.4
DWP–S5–10	.22	.23	.2	--	ND	ND	.004	ND	ND	ND

[1] Sample diluted during analysis.

[2] Estimated.

[3] Erroneous value because of cloudy sample.

[4] Erroneous value because of new well construction.

Table 5. Mean first-order decay rates and computed half-lives for trichloroethene, dichloroethene, and vinyl chloride under five oxidation-reduction conditions (Suarez and Rifai, 1999)

[--, no data]

Oxidation-reduction condition	Trichloroethene day^{-1}	Half-life (days)	Dichloroethene (all isomers) day^{-1}	Half-life (days)	Vinyl chloride day^{-1}	Half-life (days)
Oxygen reduction (aerobic oxidation)	0.005	139	--	--	0.087	7.97
Nitrate reduction (denitrification)	--	--	--	--	--	--
Iron reduction	.003	231	0.002	347	.26	2.67
Sulfate reduction	.011	63	.045	15.4	--	--
Carbon dioxide reduction (methanogenesis)	.015	46.2	.047	14.7	.23	3.01

Oxidation-Reduction Processes in Ground Water at Naval Weapons Industrial Reserve Plant, Dallas, Texas

Appendix—Data

Appendix—Data

Field data collected by the USGS, September 1997 and March 1998

[µS, microsiemens per centimeter at 25 degrees Celsius; mM, millimolar; µM, micromolar; mg/L, milligrams per liter; ND, not detected; --, not analyzed]

September 1997					March 1998					
Well number	**Specific conductance (µS)**	**pH (standard units)**	**Carbon dioxide (mM CO_2)**	**Methane (µM CH_4)**	**Well number**	**Specific conductance (µS)**	**pH (standard units)**	**Alkalinity, bicarbonate (mg/L HCO_3)**	**Carbon dioxide (mM CO_2)**	**Methane (µM CH_4)**
DWP–10–1	950	6.88	0.01	ND	DWP–10–1	703	6.61	455	1.62	291.2
DWP–10–DW4	910	6.77	.48	ND	DWP–10–2	846	7.25	478	1.28	371.3
DWP–1–13	6,080	7.51	1.77	7.87	DWP–10–6	720	7.13	405	1.18	ND
DWP–128–1	930	6.74	2.17	34.20	DWP–10–DW1	1,103	7.40	401	.66	.3
DWP–1–9	970	7.39	1.57	ND	DWP–10–DW4	1,178	7.08	398	.42	ND
DWP–4–10	1,150	6.6	3.75	.87	DWP–10–DW6	803	7.22	371	1.00	ND
DWP–4–14	1,030	6.56	2.21	ND	DWP–1–13	1,101	6.95	528	1.55	3.9
DWP–4–2	--	--	2.23	ND	DWP–128–1	1,104	6.94	638	2.48	234.5
DWP–4–4	--	--	1.94	61.49	DWP–1–9	1,126	6.50	459	1.47	ND
DWP–4–5	1,160	6.75	2.28	.46	DWP–4–10	1,220	6.82	646	3.09	35.5
DWP–4–8	920	7.9	1.22	ND	DWP–4–14	1,122	6.73	485	2.43	3.7
DWP–4–9	1,210	6.61	2.67	ND	DWP–4–2	1,228	6.81	516	2.13	ND
DWP–5–12	705	6.86	1.20	72.12	DWP–4–4	995	6.77	520	1.85	97.1
DWP–5–13	677	6.77	1.29	.57	DWP–4–5	1,160	6.79	559	2.15	ND
DWP–7–6	--	--	1.89	2.86	DWP–4–8	930	6.99	476	1.15	ND
DWP–BG–10	830	6.74	2.33	ND	DWP–4–9	1,210	6.84	540	2.13	ND
DWP–BG–4	1,160	7.91	1.19	ND	DWP–5–12	802	6.92	450	.41	102.5
DWP–BG–4–3	1,030	6.79	1.58	ND	DWP–5–13	798	6.81	379	1.13	.7
DWP–BG–4–6	1,190	7.72	1.10	ND	DWP–7–6	976	6.80	469	1.36	ND
DWP–BG–6	798	6.43	1.94	ND	DWP–BG–10	1,036	6.58	521	2.38	ND
DWP–BG–7	1,240	6.61	2.84	ND	DWP–BG–4	1,028	6.97	418	1.09	ND
DWP–BG–8	1,050	7.84	2.11	ND	DWP–BG–4–3	1,090	6.80	481	1.59	ND
DWP–DBG–3	1,050	7.84	1.39	ND	DWP–BG–4–6	1,002	6.95	479	1.29	ND
DWP–L1–5	717	6.86	.69	447.55	DWP–BG–6	924	6.98	428	1.85	ND
DWP–L2–1	741	6.96	1.08	ND	DWP–BG–7	1,138	6.86	516	3.13	ND
DWP–L2–16	757	7.02	.74	ND	DWP–BG–8	1,031	7.11	513	1.50	ND
DWP–L2–4	--	--	.36	ND	DWP–DBG–3	991	6.85	447	1.32	ND
DWP–L2–5	--	--	1.19	ND	DWP–L1–5	700	7.07	455	.70	935.2

Field data collected by the USGS, September 1997 and March 1998—Continued

September 1997					March 1998					
Well number	Specific conductance (µS)	pH (standard units)	Carbon dioxide (mM CO_2)	Methane (µM CH_4)	Well number	Specific conductance (µS)	pH (standard units)	Alkalinity, bicarbonate (mg/L HCO_3)	Carbon dioxide (mM CO_2)	Methane (µM CH_4)
DWP–L2–8	980	6.93	ND	ND	DWP–L2–1	949	7.22	327	1.63	ND
DWP–L2–DW1	1,620	11.08	.10	ND	DWP–L2–16	937	6.90	504	1.02	ND
DWP–L2–DW2	825	7.14	1.01	6.66	DWP–L2–4	613	7.12	216	.34	ND
DWP–OFF–10	921	6.68	2.68	ND	DWP–L2–5	1,055	6.95	385	1.16	ND
DWP–OFF–11	1,240	6.59	3.34	ND	DWP–L2–8	1,020	6.84	413	1.63	ND
DWP–OFF–5	1,490	6.33	2.01	2.89	DWP–L2–DW1	4,000	11.84	289	ND	.5
DWP–S1–10	865	6.67	1.51	32.34	DWP–L2–DW2	889	7.02	411	1.17	142.2
DWP–S1–11	--	--	1.28	ND	DWP–OFF–10	1,169	6.87	529	2.84	ND
DWP–S1–17	628	6.98	3.08	3.75	DWP–OFF–11	1,194	6.87	546	2.89	ND
DWP–S1–18	734	6.6	.99	ND	DWP–OFF–12	905	6.93	481	2.60	493.2
DWP–S1–4	734	6.79	2.26	6.71	DWP–OFF–14	903	7.91	496	.76	.9
DWP–S1–5	--	--	1.34	ND	DWP–OFF–5	1,557	7.00	498	2.21	1.5
DWP–S1–7	1,170	7.33	1.81	ND	DWP–S1–10	921	6.78	470	1.42	37.7
DWP–S1–DW1	--	--	.95	ND	DWP–S1–11	870	6.89	423	1.27	ND
DWP–S1–DW2	--	--	.01	ND	DWP–S1–17	683	7.09	368	1.15	34.7
DWP–S2–11	950	7.65	2.43	3.62	DWP–S1–18	787	6.90	397	.94	.8
DWP–S2–16	960	6.87	1.93	43.60	DWP–S1–4	924	6.95	334	2.00	ND
DWP–S2–18	765	6.75	1.96	ND	DWP–S1–5	849	7.19	403	1.27	ND
DWP–S2–2	936	7.6	1.73	.93	DWP–S1–7	950	6.87	433	1.67	ND
DWP–S2–5	699	6.95	2.08	132.75	DWP–S1–DW1	792	7.23	411	.92	.6
DWP–S2–DW1	1,510	7.03	.59	ND	DWP–S1–DW2	1,497	11.63	78	ND	14.2
DWP–S2–DW2	756	7.09	.46	ND	DWP–S2–11	1,031	6.79	456	2.29	ND
DWP–S5–10	1,240	6.71	2.83	ND	DWP–S2–16	920	6.95	501	1.82	78.9
					DWP–S2–18	931	6.80	516	1.88	ND
					DWP–S2–2	1,005	6.88	491	1.72	1.9
					DWP–S2–5	923	6.80	518	2.25	439.4
					DWP–S2–DW1	1,584	7.13	420	.60	214.0
					DWP–S2–DW2	1,231	7.01	395	1.46	1.4
					DWP–S5–10	1,038	6.83	520	2.24	ND

Data from EnSafe/Allen & Hoshall contract laboratory, September 1997

[mg/L, milligrams per liter; µg/L, micrograms per liter; ND, not detected; --, not analyzed]

Well number	Dissolved solids, calculated (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Iron (mg/L)	Manganese (mg/L)	Tetrachloroethene (µg/L)	1,1-Dichloroethene (µg/L)	1,1,1-Trichloroethane (µg/L)	1,1-Dichloroethane (µg/L)	Benzene (µg/L)	Toluene (µg/L)
DWP–10–1	416	82.3	13.5	48.7	1.47	11.3	0.795	ND	ND	ND	ND	ND	ND
DWP–10–DW1	--	103	11	120	3.30	3.36	.336	7	ND	ND	9	ND	7
DWP–10–DW4	771	117	8	84.6	1.54	.267	.386	ND	ND	ND	ND	ND	ND
DWP–10–DW6	--	99	5.44	81.4	3.75	1.56	.196	ND	ND	ND	ND	ND	ND
DWP–1–13	722	135	9.24	121	1.19	.178	.073	ND	3	ND	ND	ND	ND
DWP–128–1	568	110	6.5	103	1.81	.86	1.43	ND	4	ND	2	ND	ND
DWP–1–9	762	115	9.37	106	1.19	.122	.039	ND	ND	ND	ND	ND	ND
DWP–4–10	763	134	14.6	137	.475	.93	1.67	ND	1	ND	ND	ND	ND
DWP–4–14	723	181	10.7	67.4	1.31	.035	.022	ND	ND	ND	ND	ND	ND
DWP–4–2	--	--	--	--	--	--	--	ND	ND	ND	ND	ND	ND
DWP–4–4	--	--	--	--	--	--	--	ND	ND	ND	ND	ND	ND
DWP–4–5	724	109	7.67	150	1.06	.039	.29	ND	ND	ND	ND	ND	ND
DWP–4–8	574	83.1	6.5	109	1.03	.106	.009	ND	ND	ND	ND	ND	ND
DWP–4–9	732	108	7.69	136	.9	.026	.007	ND	ND	ND	ND	ND	ND
DWP–5–12	463	62.9	5.31	104	.56	1.71	.948	ND	ND	ND	ND	ND	ND
DWP–5–13	528	102	6.32	62.9	1.9	.029	.006	3	3	ND	ND	ND	ND
DWP–7–6	--	--	--	--	--	--	--	ND	ND	ND	ND	ND	ND
DWP–BG–10	617	109	5.58	115	1.37	.102	.006	ND	ND	ND	ND	ND	ND
DWP–BG–4	604	92.2	5.64	109	1.3	.11	.009	98	ND	ND	ND	ND	ND
DWP–BG–4–3	697	113	11.6	128	1.86	.019	.005	43	ND	ND	ND	ND	ND
DWP–BG–4–6	584	66.3	5.49	144	1.25	.061	.002	ND	ND	ND	ND	ND	ND
DWP–BG–6	564	151	6.09	33	1.36	.69	.013	ND	ND	ND	ND	ND	ND
DWP–BG–7	717	136	7.82	119	.99	.049	.001	ND	ND	ND	ND	ND	ND
DWP–BG–8	625	80.9	3.44	146	.825	.146	.003	ND	ND	ND	ND	ND	ND
DWP–DBG–3	603	82.6	3.51	147	.846	.166	.003	ND	ND	ND	ND	ND	ND
DWP–L1–5	426	46.5	3.6	117	.74	3.55	.36	ND	ND	ND	ND	7	ND
DWP–L2–1	502	117	6.1	85.8	.9	.25	.05	ND	200	ND	ND	ND	ND

Data from EnSafe/Allen & Hoshall contract laboratory, September 1997—Continued

Well number	Dissolved solids, calculated (mg/L)	Calcium (mg/L)	Magnesium (mg/L)	Sodium (mg/L)	Potassium (mg/L)	Iron (mg/L)	Manganese (mg/L)	Tetrachloroethene (µg/L)	1,1-Dichloroethene (µg/L)	1,1,1-Trichloroethane (µg/L)	1,1-Dichloroethane (µg/L)	Benzene (µg/L)	Toluene (µg/L)
DWP–L2–16	438	97.3	5.62	67.3	0.88	0.36	0.009	ND	54	ND	12	ND	ND
DWP–L2–4	345	87.6	4.5	36.2	1.08	5.18	.14	ND	ND	ND	ND	ND	ND
DWP–L2–5	--	--	--	--	--	--	--	ND	ND	ND	ND	ND	ND
DWP–L2–8	693	118	8.65	98	1.21	.32	.01	ND	ND	ND	ND	ND	ND
DWP–L2–DW1	774	3.15	.67	167		.102	.006	ND	3	ND	ND	ND	ND
DWP–L2–DW2	607	88.2	8.01	108	4.41	5.75	.453	ND	ND	ND	ND	ND	ND
DWP–OFF–10	734	143	8.53	118	1.2	.37	.009	6	ND	ND	ND	ND	ND
DWP–OFF–11	805	156	8.73	127	1.42	.31	.008	ND	ND	ND	ND	ND	ND
DWP–OFF–12	--	158	8.71	28.7	2.2	.704	.496	ND	ND	ND	ND	ND	ND
DWP–OFF–14	--	161	9.4	39.4	3.2	7.21	2.36	ND	ND	ND	ND	ND	ND
DWP–OFF–5	1,001	138	13.7	200	1.88	.322	.03	170	ND	ND	ND	ND	ND
DWP–S1–10	551	112	5.78	81.9	1.73	.19	.085	1	77	ND	11	ND	ND
DWP–S1–11	--	--	--	--	--	--	--	ND	ND	ND	ND	ND	ND
DWP–S1–17	384	81.2	7.4	54.5	1.2	3.28	.77	ND	ND	ND	ND	ND	ND
DWP–S1–18	411	76.1	4.17	93	.99	.23	.006	1	70	ND	27	ND	ND
DWP–S1–4		120	7.43	75.1	.68	.18	.15	.9	270	ND	110	ND	ND
DWP–S1–5	--	--	--	--	--	--	--	ND	ND	ND	ND	ND	ND
DWP–S1–7	598	119	7.2	103	1.07	.11	.006	8	1,100	18	60	ND	ND
DWP–S1–DW1	--	--	--	--	--	--	--	ND	ND	ND	ND	ND	ND
DWP–S1–DW2	--	--	--	--	--	--	--	ND	ND	ND	ND	ND	ND
DWP–S2–11	614	122	5.94	95.3	.97	.18	.014	ND	5	ND	4	1	ND
DWP–S2–16	564	93.5	9.05	99.9	1.29	2.06	1.22	ND	12	ND	ND	ND	ND
DWP–S2–18	578	103	9.46	98.8	2.23	1.73	.096	ND	2	2	ND	ND	ND
DWP–S2–2	624	91.6	6.64	136	2.18	1.77	.81	ND	8	ND	25	ND	ND
DWP–S2–5	558	94.4	7.66	101	2.65	5.32	1.52	ND	4	ND	ND	ND	ND
DWP–S2–DW1	1,264	105	18	295	6.47	1.93	.143	ND	ND	ND	ND	ND	ND
DWP–S2–DW2	603	87.5	10.3	97.2	3.77	.375	.269	ND	ND	ND	ND	ND	ND
DWP–S5–10	694	140	9.24	96.9	1.06	.019	.002	ND	ND	ND	ND	ND	ND

Data collected by USGS and analyzed by Quanterra Laboratories, September 1997

[mg/L, milligrams per liter; ND, not detected]

Well number	Alkalinity, bicarbonate (mg/L HCO_3)	Sulfate (mg/L SO_4)	Chloride (mg/L Cl)	Fluoride (mg/L F)	Silica (mg/L SiO_2)	Nitrate nitrogen (mg/L NO_3)	Nitrate plus nitrite nitrogen (mg/L $NO_3 + NO_2$)	Ammonia nitrogen (mg/L NH_4)	Orthophosphate phosphorus (mg/L PO_4)	Boron (mg/L B)	Total organic carbon (mg/L)
DWP–10–1	449	4.9	16.6	ND	12.2	ND	ND	1.1	ND	0.12	7.3
DWP–10–DW4	387	326	21.5	ND	17.8	ND	ND	1	ND	.89	ND
DWP–1–13	491	146	42.4	1	21.6	ND	ND	ND	ND	.35	1.3
DWP–128–1	318	104	61.9	1.3	19.7	1.2	1.4	.47	ND	.26	3.8
DWP–1–9	460	115	52.6	1.2	21.3	ND	.39	ND	ND	.27	ND
DWP–4–10	690	70.1	40.2	ND	19.1	ND	ND	.23	.42	.56	2.4
DWP–4–14	519	124	55	ND	23.6	ND	ND	.3	.51	.29	ND
DWP–4–2	546	141	18.7	ND	25.3	2.8	3.4	ND	.16	.27	2.4
DWP–4–4	478	86.5	39.1	ND	17.3	ND	ND	2.2	ND	.3	1.6
DWP–4–5	554	120	34.8	ND	24.1	1.6	1.8	ND	ND	.31	ND
DWP–4–8	472	92.3	24.5	.58	21.1	1.1	1.3	ND	.22	.25	ND
DWP–4–9	581	135	29.9	ND	23.7	ND	.46	.21	.14	.29	2.5
DWP–5–12	433	5.9	42.6	1.7	22.1	ND	ND	.11	ND	.35	2.9
DWP–5–13	375	57.8	24.7	1.4	22.8	ND	ND	ND	ND	.2	ND
DWP–7–6	500	67.7	28.4	.83	24.6	1	1.1	ND	ND	.26	ND
DWP–BG–10	522	69.5	30.2	.65	24.8	2.3	2.4	ND	ND	.3	ND
DWP–BG–4	410	133	34.9	.97	22.6	2	2.4	ND	.12	.18	ND
DWP–BG–4–3	480	148	32.1	.95	22.4	1.9	2.1	ND	ND	.2	ND
DWP–BG–4–6	441	86.8	38.3	1.1	21.4	1.2	1.4	ND	.056	.19	ND
DWP–BG–6	427	102	31.5	.64	24.6	2.6	2.7	ND	ND	.1	ND
DWP–BG–7	538	105	53.4	.65	26.2	1	1.4	ND	.61	.2	ND
DWP–BG–8	514	84.5	28.4	1.1	23.4	2.1	2.2	ND	ND	.22	ND
DWP–DBG–3	455	55.6	64	1.1	21.4	ND	ND	.17	ND	.27	2.5
DWP–L1–5	395	ND	42.2	1.5	15	ND	ND	1.2	ND	.26	5
DWP–L2–1	337	71.2	29.1	.76	23.4	25	26.1	ND	ND	.23	ND

Data collected by USGS and analyzed by Quanterra Laboratories, September 1997—Continued

Well number	Alkalinity, bicarbonate (mg/L HCO_3)	Sulfate (mg/L SO_4)	Chloride (mg/L Cl)	Fluoride (mg/L F)	Silica (mg/L SiO_2)	Nitrate nitrogen (mg/L NO_3)	Nitrate plus nitrite nitrogen (mg/L $NO_3 + NO_2$)	Ammonia nitrogen (mg/L NH_4)	Orthophosphate phosphorus (mg/L PO_4)	Boron (mg/L B)	Total organic carbon (mg/L)
DWP–L2–16	271	75.4	33.7	0.82	22.3	14.8	15.6	ND	ND	0.18	ND
DWP–L2–4	218	42.7	37.3	.79	20.9	3.2	3.5	ND	ND	.18	ND
DWP–L2–5	386	108	59	ND	25.1	8.4	9.5	ND	ND	.25	ND
DWP–L2–8	682	79.3	20.5	1.5	25.8	ND	ND	.93	ND	.37	2.9
DWP–L2–DW1	406	128	41.5	ND	27.6	3.9	4.2	ND	ND	.21	ND
DWP–L2–DW2	497	60	54.2	2.5	29.8	ND	ND	ND	ND	.31	11.9
DWP–OFF–10	528	107	66.6	.68	25.2	2.8	3.1	ND	ND	.19	ND
DWP–OFF–11	538	123	95.2	ND	24.4	1.5	1.8	ND	.091	.19	1
DWP–OFF–5	495	278	96.1	ND	25.8	2.3	2.7	ND	.18	.22	ND
DWP–S1–10	425	71.8	43.3	ND	21.5	2.1	2.5	ND	ND	.22	ND
DWP–S1–11	422	88.7	21.3	.65	21.9	ND	.25	ND	ND	.58	ND
DWP–S1–17	348	25.5	18.1	1.6	17.9	ND	.12	.87	ND	.18	2.3
DWP–S1–18	271	54.8	22.9	.83	23.2	2	2.4	ND	ND	.22	ND
DWP–S1–4	372	62.9	33.8	1.3	25.5	ND	ND	ND	ND	.2	ND
DWP–S1–5	398	59.8	35.1	1.4	23.2	1.7	2.1	ND	ND	.21	ND
DWP–S1–7	442	85.5	35.1	.75	26.2	1.5	1.9	.5	ND	.21	1.1
DWP–S1–DW1	247	55.7	27.7	.89	21.9	ND	ND	.89	ND	.52	4.7
DWP–S1–DW2	420	61.6	19	ND	20.2	ND	ND	.32	ND	.6	ND
DWP–S2–11	488	75.8	45	ND	24.5	ND	.35	ND	ND	.22	ND
DWP–S2–16	494	60	30.4	.64	19.1	ND	ND	.42	.12	.21	ND
DWP–S2–18	520	59.2	21.3	.83	22.3	ND	.12	.41	.57	.23	ND
DWP–S2–2	520	65	38.7	.78	21	ND	ND	.21	.41	.27	ND
DWP–S2–5	513	32.3	39.1	.59	18	ND	ND	1.9	.18	.21	1.9
DWP–S2–DW1	389	594	32.3	1.8	16.5	ND	ND	1.4	ND	1.7	11.7
DWP–S2–DW2	293	220	21.2	.69	15.4	ND	ND	.37	.083	.42	ND
DWP–S5–10	494	130	45.4	.65	24.4	1.6	1.8	ND	.094	.18	ND