

4.0 Operable Unit 1, the Front Street Site

The following sections describe the history and the current understanding of the extent and magnitude of PCE contamination at OU1. Site-specific factors that affect the fate and transport of PCE at the site, including the direction and expected rate of contaminant migration from the site, also are discussed. In addition, a summary of the Human-Health and Ecological Risk Assessments is presented.

4.1 Background of Operable Unit 1

4.1.1 Location and Physical Setting of OU1

Operable unit OU1 (the Front Street site) is on the northeast corner of the intersection of Front Street and Cottonwood Street in downtown New Haven (fig. 4-1). The site consists of a 15,000 ft² (square foot), one-story building, a vacant lot east of the building, and a vacant lot west of the building on the west side of Cottonwood Street. The building lot is level with less than 1.5 ft of relief. Runoff from the southwest and west sides of the building drains to a storm sewer located in the street at the intersection of Front and Cottonwood Streets. Runoff appears to pool along the southeast side of building and on the nearly level grass and gravel areas surrounding the loading dock. The loading dock is a shallow (3-ft deep) gravel-covered area with a concrete ramp. Front Street occupies a city easement across the south side of the building. Front Street provides access to a boat ramp on the Missouri River about 500 ft northeast of the site and to the city sewage lagoon east of the site.

4.1.2 Site History

Several industries have operated at the site since the 1950's and the Front Street building was built in at least five phases (fig. 4-1). No buildings are evident at the site on a 1945 aerial photograph (not shown), and the site appears to be a fruit-tree orchard with a house site at the southeast corner of the present building. Long-term residents indicated that the "machine shop," as the Front Street building was originally known, was built sometime in the 1940's. Interviews of local residents by the USEPA determined that the machine shop was a small metalworking business. The flood protection levee around downtown New Haven had not been built in 1945.

By 1958, most of the western one-half of the building had been built, and an "L-shaped" house is clearly visible under what would become the southeast corner of the Front Street building (fig. 4-2). The construction of Phases I and II by 1958 corresponds to the opening of a large fabric and tent manufacturing facility operated by the Hawthorne Company (later to become part of the Kellwood

Company) in New Haven in the 1950's. During the 1950's, the machine shop became known as NHMC and began fabricating metal tent poles for the Hawthorne Company. According to interviews with former employees, by the late 1960's metal fabrication for the Hawthorne Company was NHMC's sole business. An inspection of the cinder-block part of the building indicates that it was constructed in at least three phases with the restroom area on the northwest corner added between 1960 and 1965 (1965 aerial photograph not shown). The oldest section (Phase I, fig. 4-1) was the original "machine shop," which appears to be the southwest quarter of the building visible on the 1958 aerial photograph (fig. 4-2). Former employees indicate that tube "swaging" operations were conducted in this area. PCE was used in the swaging area to remove lubricating oils from the fabricated metal poles. The area between the house and the cinder block building on the 1958 photograph is moderately reflective and probably is gravel. Stacks of materials or vehicles appear to be present near the gravel (fig. 4-2). The house appears to have been demolished by the time the 1960 aerial photograph was taken. The flood-protection levee and a bulk fuel off-loading facility (fig. 4-2) along the north side of the railroad tracks about 200 ft south of the Front Street building was built between 1945 and 1958.

By 1965 (photograph not shown), the eastern part of the building (Phases IV and V) had been built as shown on the 1968 aerial photograph (fig. 4-3). A seam in the concrete pad inside Phase V with paint markings on the floor indicate that the concrete beneath the east part of Phase V, at one time, may have been an outside loading dock or material staging area. A shallow drainage ditch is visible on the 1958, 1960, 1965, 1968, and 1970 aerial photographs along the east side of the building. According to the city utilities department, a small culvert once extended beneath Front Street to carry surface runoff from the south side of the street to the ditch along the east side of the building. Runoff from Front Street south of Phases IV and V of the current (2002) building apparently flowed east along the south side of Front Street and north through this culvert into the ditch. The USEPA learned that waste PCE and dirt were washed out of the south doors in the Phase I area of the building. The water and waste PCE reportedly drained south and east and pooled in low areas on the south side of Front Street.

The building and surrounding area remained relatively unchanged through 1986 (fig. 4-4). The concrete pad east of the building and the loading dock had not yet been built. The drainage ditch east of the building was filled sometime between 1979 and 1984 (photograph not shown), and runoff was diverted to a relocated ditch about 60 ft east of the former ditch (fig. 4-4). The former ditch appears level and covered with grass in the 1986 aerial photograph, which was taken when Riverfront Industries operated. Several vehicles, a stack of machinery or materials, and two circular objects that

may be tanks or stacks of drums also are visible along the south and east sides of the building (fig. 4-4). Mosby (1988) found that paint wastes and used solvent (unknown type) were dumped on the ground behind the building. During a reconnaissance of the site in 1999, parts of the concrete-lined ditch along the north side of the building were stained with various colors (blue, red, and green), and this ditch may correspond with the dumping location discovered by Mosby (1988). The bulk fuel facility along the railroad track is still visible in the 1986 photograph.

During September 1987, the MDNR conducted a PA of OU1, which was then called the New Haven Public Water Supply Site (Singleton, 1987). Interviews during the PA confirmed that prior to 1958 a machine shop operated at the Front Street site (Struckhoff, 1989). From 1958 to 1972, the Front Street site was owned by NHMC. The Kellwood Company (formerly the Hawthorne Company) purchased a partial interest in NHMC in 1972 and 6 months later, because of increased production demands, purchased all of NHMC and moved tubing operations to a new facility on south Industrial Drive (fig. 1-8) in southern New Haven, which is now part of OU2 (the Kellwood site). Between 1983 and 1989, Riverfront Industries occupied the building and manufactured furniture for nursing homes and hospitals and may have used PCE and paint solvents. Tenants occupying the facility after Riverfront Industries included Transportation Specialists Inc. (1989-1993) and Wisser Enterprises Inc. (1997-2002). Transportation Specialists Inc. excavated a large concrete sump inside the building in Phase V that served as an oil bath to cool heat-tempered truck springs (fig. 4-1). According to MDNR and USEPA records, Transportation Specialists Inc. and Wisser Enterprises Inc. did not use PCE in their operations. However, automotive brake cleaner that occasionally is used by Wisser Enterprises Inc. [16-oz (ounce) aerosol cans] does contain PCE. The industries that have operated at the Front Street site with their potential for PCE usage are summarized in table 4-1.

Table 4-1. Summary of industries that have operated at the Front Street site.

[PCE, tetrachloroethene; TCE, trichloroethene; ?, dates uncertain]

Dates	Industry	Operations	PCE Usage
1947-1958	Local machine shop	General machinery repair	None
1958-1972	New Haven Manufacturing Company (NHMC)	Tube swaging and cleaning	Large quantities used
1972-1972	Kellwood Company	Machinery repair, tube operations moved to OU2	Possible use
1972-1983	Unknown	Unknown	Unknown
1983-1989?	Riverfront Industries	Furniture manufacturing and painting	Possible solvent use (PCE or TCE) in painting operations
1989-1993	Transportation Specialists Inc. (TSI)	Truck spring fabrication	None
1997-2002	Wiser Enterprises	Boat and automobile repair	Occasional use as aerosol brake cleaner (16-ounce spray cans)

4.1.3 Previous Environmental Sampling at OU1

During 1988 and 1989, the MDNR collected four soil samples from OU1 (Missouri Department of Natural Resources, 1988, 1989). PCE was detected in soil samples at concentrations of 6.1, 41, 72, and greater than 6,500 µg/kg. The locations of the MDNR samples are unknown, but according to Jacobs Engineering Group, Inc. (1994), the samples were collected from beneath the concrete pad on the east side of the building. A composite sample also was collected from liquids in several drums stored at the facility and analyzed for metals, VOCs, and flashpoint; however, the VOC analysis was not reported. The liquid sample did not contain detectable metals and had a low flashpoint (21 °C), indicating the presence of a volatile, flammable, organic solvent such as methyl isobutyl ketone (flashpoint of about 18 °C) or pyridine (flashpoint of about 20 °C). According to the National Institute for Occupational Safety and Health (Montgomery, 1991), PCE is a non-combustible solvent; therefore, the low flashpoint of the sample suggests the composite liquid sample from the drums did not contain a large fraction of PCE.

The ESI included an extensive photograph documentation of the site, as it existed in 1993. During the time the ESI was conducted, Transportation Specialists Inc. manufactured truck springs at the site. ESI investigators noted that a concrete pad (20 by 100 ft) had recently been constructed on the east

side of the building and probably over the area where the MDNR had previously collected soil samples during 1988 and 1989. The concrete loading dock on the east side of the building also had been constructed since the MDNR sampling. During November 1993, 15 soil samples were collected from hand-augered boreholes at 9 locations near the building (fig. 4-1). Boreholes were installed to depths of 9 ft or less and were screened for the presence of PCE using a total organic vapor analyzer (OVA) and PCE-specific detector tubes. Based on the results of the field screening, soil samples were collected from eight boreholes for laboratory analyses of VOCs. No soil samples were collected from borehole 4S because the field screening did not indicate the presence of organic vapors or PCE. The maximum PCE concentration detected was 83,000 J $\mu\text{g}/\text{kg}$ at 6.0-6.5 ft deep in borehole 1S (table 4-2). The J qualified indicates an estimated concentration below the reporting limit. In general, PCE concentrations were larger in deep samples than in shallow samples.

Table 4-2. Summary of tetrachloroethene (PCE) concentrations in subsurface soil samples collected at Operable Unit OU1 by U.S. Environmental Protection Agency contractors during 1993.

[ft bls, feet below land surface; $\mu\text{g}/\text{kg}$, micrograms per kilogram; J, estimated concentration below the reporting limit; --, no data available; <, less than]

Location number (fig. 4-1)	Depth (ft bls)	R_north Coordinate (approximate distance, in ft, north from the southeast corner of the building)	R_east Coordinate (approximate distance, in ft, east from the southeast corner of the building)	PCE concentration ($\mu\text{g}/\text{kg}$)
1S	2.0-2.5	-3	0	23,000 J
	6.0-6.5	-3	0	83,000 J
2S	4.0-4.5	0	26	7,200 J
	6.0-6.5	0	26	24,000 J
3S	6.0-6.5	88	27	39
4S	--	104	-77	--
5S	5.5-6.0	0	60	930
6S	4.0-4.5	25	26	490
	5.5-6.0	25	26	1,100
	5.5-6.0 (duplicate)	25	26	2,000
	8.25-8.75	25	26	2,800 J
7S	2.0-2.5	12	26	610
	4.0-4.5	12	26	<1,500
	6.0-6.5	12	26	5,800
8S	2.0-2.5	-11	13	60,000 J
9S	1.75-2.3	-45	14	<12

4.2 RI Investigations at Operable Unit 1

In order to provide a comprehensive picture of the extent and magnitude of contamination, the following sections include a discussion of all data collected at OU1 by the USGS during the ESI/RI (1999-2000) and RI (2000-2002). Where relevant, data collected during previous investigations at OU1 also are included. Parts of several investigative activities at OU1 were done concurrently because the results from one activity affected decisions regarding sampling locations for another activity. An initial site visit was made during the ESI/RI in early 1999, at the time the well inventory discussed in section 1.2.4 was being done. The initial site visit included the collection of tree-core samples from several trees in the vicinity of the site and ground-water samples from two nearby domestic wells. Based on the result of the initial tree-core and domestic well sampling, four monitoring wells were installed in the alluvial aquifer at the site in 1999. Surface-water, storm-sewer, and sanitary-sewer sampling at OU1 were done during 2000 and 2001. Intensive soil and ground-water sampling was done during 2001 and 2002. The Ecological and Human-Health Risk Assessments were conducted in 2002. The following is a summary of the chronology of the major ESI/RI and RI data collection efforts at OU1:

<u>Activity</u>	<u>Dates</u>	<u>Investigation</u>	<u>Agency</u>
Vegetation (tree core) sampling	1999-2002	ESI/RI, RI	USGS
Well drilling and ground-water sampling	1999-2002	ESI/RI, RI	USGS
Soil sampling (limited)	1999	ESI/RI	USGS
Soil sampling (extensive)	2001-2002	RI	USGS
Surface-water, storm-, and sanitary-sewer sampling	2000-2001	ESI/R, IRI	USGS
Title search and interviews	2000-2001	RI	USEPA
Ecological Risk Assessment	2002	RI	USEPA
Human-Health Risk Assessment	2002	RI	MDHSS

4.2.1 Site Reconnaissance and Tree-Core Sampling

A reconnaissance of the site was made in the spring of 1999 during the ESI/RI (U.S. Environmental Protection Agency, 2001). At the time of the reconnaissance, the property had been recently purchased by an individual who operated a small automotive repair business and sold methanol-based automobile racing fuels. The inside of the building was filled with scrap automobile parts, empty drums of methanol (racing fuel), and 10 to 20 old automobiles in various states of disrepair. What may have been a steel floor drain was observed in area 2, and a large (10 by 15 ft) rectangular dirt-

filled hole in the concrete inside Phase 5 was present near the southeast corner of the building (fig. 4-1). The owner indicated that the dirt-filled area was a 7 to 8 ft deep concrete-lined sump that the previous tenant (Transportation Specialists Inc.) had used as an oil bath to cool heat-treated truck springs. The sump apparently had been inspected by the MDNR before the current owner purchased the property and contained no visible cracks. The owner had filled in the sump with scrap metal, demolition debris, gravel, and dirt to facilitate moving automobiles inside the east part of the building. The metal cooling water tanks, evaporators, propane tanks, and drums that were present on the east side of the building near the loading dock during the ESI (Jacobs Engineering Group, Inc., 1994) had been removed. The loading dock area contained several wrecked automobiles, pickup trucks, and several flat-bed trailers. One rusty 55-gal bung-top drum was next to a rack on the northwest side of building. The drum contained a small amount of an oily residue. The lot east of the loading dock was covered with grass and barren gravel near the flood protection levee. Metal debris that included nails, bolts, and parts of truck springs were scattered on the surface or partially buried in the lot. No evidence of PCE usage was observed at the site except for several 16-oz aerosol cans of automotive brake cleaner occasionally used by the current property owner. A concrete-lined ditch on the north side of the building had several stains that appeared to be related to the dumping of paint wastes reported previously during the ESI (Jacobs Engineering Group, Inc., 1994).

Activities during the initial site visit included the collection and analyses of tree-core samples for PCE and other VOCs and the sampling of a hand dug well (TW-E) on private property immediately north of the Front Street Building. Tree-core sampling was conducted throughout the ESI/RI and RI as access to additional parcels became available. The USEPA initiated an extensive title search of parcels of land at OU1 to establish the property ownership history and located and interviewed former employees of the owners and tenants who operated businesses at the property.

Generally, the largest estimated PCE concentrations were detected in trees along the north side of the Front Street site building (fig. 4-5). A single tree along the south side of the building had the largest estimated PCE concentration (greater than 5,000 $\mu\text{g}/\text{kg}$). Several trees between the site and the Missouri River also contained PCE (fig. 4-5). No PCE was detected in trees in the vicinity of the former dry cleaner or in trees west of OU1 near public-supply well W1. Based on the results of the tree-core sampling and a general understanding of ground-water flow in the alluvial aquifer (section 1.5.3), a conceptual model was developed to account for soils and ground water in the Missouri River alluvial aquifer that were contaminated with PCE. The conceptual model was that a plume of PCE-contaminated ground water extended from the southeast side of the Front Street building beneath private property north of the site toward a boat ramp on the Missouri River (fig. 4-5).

4.2.2 Soil Investigation

Subsurface soil investigations at OU1 were conducted in three phases:

- Phase I, preliminary USEPA soil borings to 8 ft deep, June 2000 (40 borings),
- Phase II, ESI/RI grab and hand-auger samples during USEPA removal action, July-August 2000 (52 locations), and
- Phase III, RI subsurface soil borings, January 2001-March 2002 (44 borings).

Soil-sampling locations, soil physical data, and soil analytical data are listed in Appendix OU1. The preliminary Phase I soil borings were done by the USEPA as part of an emergency removal action to replace a PCE-contaminated plastic water line that supplied a public restroom east of the Front Street building (fig. 4-6). The USEPA soil borings were located on a 30-ft rectangular grid and extended to a maximum of 8 ft deep. Sampling was done using a Geoprobe™ direct-push drill rig equipped with a 2-ft by 1-in. diameter macrocore sampler with disposable acetate sleeves. Core samples were collected at 0-2 ft, 2-4 ft, and 6-8 ft depth intervals. After removal from the sampler tube, the acetate sleeves were sliced open and an open-ended, 10-cc (cubic centimeters) disposable plastic syringe was used to collect 5 cc of soil. The soil was placed into a 40-mL (milliliter) vial containing 10 mL of deionized water and 10 mL of methanol for field analysis. Field analysis of PCE and other COCs was done with a mobile laboratory provided by the USEPA Mobile Laboratory Program (MLP). Split samples were analyzed by the USGS using a portable GC. Soil samples for laboratory analysis of VOCs were compressed into 40-mL vials to eliminate headspace, and samples to be analyzed for Resource Conservation and Recovery Act (RCRA) metals were placed in 8-oz glass jars.

Concentrations of PCE ranged from less than the MLP detection level of 2 to 914,000 µg/kg in a sample from location OU1-EPA-P-05 at 2 ft deep (fig. 4-6, table OU1-6). Soil from six locations along the south side of the Front Street building contained PCE concentrations above the health-based soil-screening level of 57,000 µg/kg. Because of the proximity of these contaminated soils to the street and additional buried utilities, the USEPA decided to excavate these soils. Excavations were limited to depths of 8 ft because the site was adjacent to a flood-protection levee. The water line was replaced and the contaminated soils excavated during July 2000. Removal of the contaminated water line required the disposal of 198 tons of PCE-contaminated soil. An additional 793 tons of PCE-contaminated soil was removed from the six areas (cells) along Front Street during July 2000 (fig. 4-6). An estimated 70 kg of PCE was removed from the site during this activity.

Phase II soil samples (fig. 4-7) were collected by the USGS from the floors of excavations and hand-augered boreholes during the removal of contaminated soils identified during Phase I activities. Samples from the floors of the excavations were taken to confirm that the remaining soil did not

contain PCE above the removal action level of 57,000 µg/kg. Samples from the floors of the excavations were collected using disposable 10-cc plastic syringes. Each syringe was pushed directly into the excavation floor, and about 5 cc of the collected soil was extruded into a 40-mL vial containing 20 mL of deionized water. The hand-auger borings extended to a maximum depth of 16 ft. Four of the hand-auger borings were located along the north side of the Front Street building and one boring was located on the south side of the building in the floor of excavated cell 25 (fig. 4-7). The hand auger was used to advance the borehole to the desired depth; then samples were collected using a 6-in. by 1.5-in. diameter stainless steel core tube with removable aluminum sleeves that was driven into the bottom of the hole. A 5-cc sample was collected from the bottom of the core tube and placed in a 40-mL vial containing 20 mL of deionized water for analysis by the USGS portable GC.

The main phase of characterization (Phase III) of subsurface soils (44 borings) was done during January–March 2001 by the USGS and a USGS contractor (PSA Environmental Inc.). Soil samples were collected for analysis of VOCs and other compounds and continuous core samples were collected for geologic logging of the alluvial aquifer at OU1. Twenty-three borings (locations G01 through G22 and G65, fig. 4-8) were drilled outside the Front Street building using a tractor-mounted Giddings™ soil-exploration auger drill rig. These borings were drilled to refusal (less than or equal to 25 ft deep), which occurred in a medium to coarse sand. Soil samples were collected with the auger rig using a 4-ft by 2-in. diameter stainless steel core barrel lined with disposable acetate sleeves. Fifteen borings (locations G50 through G64) were done inside the Front Street building and five borings were done outside the building (locations G24, G25, G26, G65, and G65B) using a track-mounted or truck-mounted Geoprobe™ drill rig. The Geoprobe™ borings were done to refusal on the surface of bedrock at the base of the alluvium. Soil samples were collected from the Geoprobe™ borings using a 2-ft by 1-in. diameter macrocore sampler or a 2-ft by 1-in diameter discrete sampler. For samples collected using the drill rigs, the acetate sleeve was sliced open after removal from the core barrel, and 5 cc of soil was collected and placed into a 40-mL vial containing 20 mL of deionized water for field analyses of PCE and other VOCs by using a portable GC. Laboratory samples were collected for the Human-Health and Ecological Risk Assessments at selected locations. These samples were analyzed for VOCs, SVOCs, metals, organo-chlorine pesticides, and PCBs previously discussed in section 1.7. All borings in proximity to the Front Street building were referenced to a temporary grid based on the southeast corner of the building referred to as the R_north and R_east coordinates (table OU1-1). No soil borings exist with ID numbers of G23 and G27 through G49.

4.2.3 Ground-Water Investigation

The ground-water investigation at OU1 included two phases of monitoring well installation and a third phase consisting of the installation and sampling of temporary wells. During Phases I and II, a total of six monitoring wells were installed in the Missouri River alluvial aquifer and two monitoring well clusters were installed in the bedrock aquifer in the vicinity of OU1 (fig. 4-9). Ground-water samples were collected from these wells and from a private hand-dug well immediately north of the Front Street building (TW-E). During Phase III a series of “direct-push” temporary wells were installed beneath the Front Street building and in the vicinity to supplement the existing monitoring well network (fig. 4-10). The following is a summary of the ground-water investigation at OU1:

- Phase I Installation of four alluvial monitoring wells (TW-A through TW-D) during 1999,
- Phase II Installation of two additional alluvial monitoring wells (TW-F and TW-G) and
 bedrock monitoring well clusters (BW-00 and BW-00A; BW-01 and BW-
 01A) during 2000, and
- Phase III Ground-water samples obtained from 21 temporary “direct-push” wells beneath
 and in the vicinity of OU1 (2000-2002) and slug tests in selected monitoring wells.

Ground-water samples were collected from monitoring wells and temporary wells and analyzed for VOCs using USEPA methods 8260 or 524.2. Generally, split samples also were analyzed by a portable GC. Samples from monitoring wells were collected using variable-speed submersible pumps. Alluvial monitoring wells typically were purged at flow rates of between 0.2 and 0.4 gal/min to minimize drawdown of the water level in the well. Bedrock monitoring wells were purged at 0.5 to 5 gal/min. Samples from temporary wells were collected using a peristaltic pump. Ground-water samples were not collected until field measurements for temperature, specific conductance, pH, and DO had stabilized. The hand-dug well (TW-E) was not purged and was sampled using a disposable bailer. Monitoring wells TW-A through TW-D were sampled shortly after their installation during the fall of 1999. Four sets of routine ground-water samples were collected in July 2000, November 2000, May 2001, and August-September 2001. Monitoring wells TW-C and TW-G also were sampled at various stages of the Missouri River to develop an understanding of the effect of river stage on contaminant concentrations in the alluvial aquifer.

Water-level recorders were installed in monitoring wells TW-A, TW-C, TW-G, and BW-01 during March 2001. These instruments consisted of submersible pressure transducers with internal data storage and recorded hourly water levels in the wells. This information was used to understand the effect of the Missouri River stage on water levels in the alluvial and bedrock aquifers at OU1 and the vicinity. Recorded water levels were downloaded to a laptop PC approximately every month, at which time manual measurements of the water levels in the wells and the Missouri River stage at the

New Haven boat ramp were made. Because the water-level recorders were not vented, measurements were corrected for barometric pressure fluctuations using barometric data from a recorder located in the New Haven City Utilities building. A linear regression of the Missouri River stages measured to the nearest 0.01 ft at the USGS continuous streamflow gaging station at Hermann, Missouri (about 11 river mi upstream) and manual measurements at the New Haven boat ramp was made to estimate the hourly Missouri River stage at New Haven (fig. 4-11). The coefficient of determination (r^2) was 0.998. The 95 percent confidence interval for the estimated water levels at the New Haven boat ramp using the regression equation was plus or minus 0.22 ft.

4.2.4 Missouri River Sampling

Water and bed-sediment samples were collected from the Missouri River in the vicinity of OU1 to determine if contaminants were migrating from OU1 to the river. Water samples were collected on September 19, 2001 along the south bank of the river upstream, adjacent to, and downstream from OU1 (fig. 4-12). Sediment samples were collected in areas likely to contain fine-grained sediments (clay and silt), such as behind spur dikes, because clay and silt tend to have larger concentrations of organic compounds and trace elements than sands and gravels. Water samples were collected 0.5 ft above the riverbed to minimize the effects of dilution because contaminated ground water from the alluvial aquifer was assumed to discharge into the river through the riverbed along the south bank of the river.

Samples were collected from a USGS water-quality sampling boat. A peristaltic pump was used to pull water samples through a polyethylene tube that was attached to a 150 lb (pound) weight that was lowered to the bottom of the river. After the collection of water samples, a petite-ponar dredge was used to collect samples of sediment from the upper 3-to 6-in. of the riverbed. Water samples and bed-sediment samples were analyzed for PCE and other VOCs. Four bed-sediment samples also were analyzed for lead because elevated lead concentrations had been detected in some soil samples collected from soil borings at OU1. The sampling effort was conducted during stable low-flow conditions of the river. Bed-sediment samples could not be collected at locations MR-02 and MR-03 because the water velocities at the bottom were too swift [more than 5.0 ft/s (foot per second)] for the dredge to work properly.

4.3 Physical Characteristics of Operable Unit 1

4.3.1 Surface Features and Utilities

The primary surface features of OU1 are the Front Street building, the concrete pad, and the loading dock on the east side of the building (fig. 4-13). The concrete pad is about 4 to 5 in. thick. A concrete pad up to 10-in. thick is present inside the recess on the south side of the building. A sanitary sewer goes from west to east along Front Street on the south side of the building to the southeast corner of the building where the sewer turns to the north and is beneath the concrete pad between the building and the loading dock. The sanitary sewer is buried 12 to 15 ft deep beneath the concrete pad. A concrete storm sewer line goes from a drop box on the south side of the railroad tracks north along the east side of the building (nearly beneath the sanitary sewer) to the Missouri River. A drop box to this storm sewer also is located on the north side of the railroad tracks and at the northeast corner of the pad on the east side of the Front Street building. A storm sewer drop box also is located in Front Street at the southwest corner of the building (fig. 4-13). Runoff entering this drop box flows to a second drop box on the west side of Cottonwood Street, then north to the Missouri River. A 3-in. iron water line (about 3 ft deep) also goes from west to east beneath Front Street to a public restroom on the top of the flood protection levee on the east side of the site. A “T” from the water line goes south to the “dog pen” hydrant. An underground natural gas pipe line is along the west side of the building on the east side of Cottonwood Street. Overhead lines from Cottonwood Street supply electric service to the building.

4.3.2 Unconsolidated Alluvial Deposits

The surface of the alluvium is gently sloping and ranges from an altitude of about 501 ft in the vicinity of well TW-A to about 495 ft near the storm drain drop box about 200 ft to northeast of well TW-D (fig. 4-13). The alluvium ranges from 0 to more than 50 ft thick in the vicinity of OU1. The edge of the alluvium is immediately south of the railroad tracks, and its thickness increases toward the Missouri River. A contour map of the top of bedrock at the base of the alluvium was constructed from monitoring-well, soil-core, and other data (fig. 4-14). The maximum thickness of alluvium (56 ft) is at OU1-GP04 on the northeast side of the sewage lagoon where the altitude of the bedrock is about 441 ft (fig. 4-14). Beneath the Front Street building, the thickness of the alluvium ranges from about 28.6 ft near the southeast part of the building (OU1-G52) to 37.5 ft in a north trending bedrock trough beneath the north-central part of the building (OU1-G66). The trough is most pronounced beneath the building but extends north from the building towards monitoring well TW-E.

The stratigraphy of the alluvium at OU1 is relatively homogeneous, consisting mostly of silt and silty-loam from 0 to about 20 ft deep, grading into fine and coarse-grained sands deeper than 20 to 25 ft (fig. 4-15). Grain-size analyses were done on 44 samples collected from borings OU1-G51, OU1-G60, and OU1-G65B (table OU1-2; fig. 4-16). Grain-size data indicate that the bottom 12 to 14 ft of the alluvium beneath the north part of the building (locations OU1-G51 and OU1-G60) consists of sand and sandy-silts (table OU1-2). Based on geologist's logs from soil borings at the site, these results are typical of the lower part of the alluvium beneath the building and east of the building. Samples from boring OU1-G65B are typical of the alluvial deposits beneath Front Street south of the Front Street building, which consist almost entirely of silt and sandy silt (table OU1-2). Although the U.S. Army Corps of Engineers (USACOE) indicates that as much as 10 to 15 ft of silty clay and clay are present in the upper part of the alluvium in the New Haven area, no appreciable thickness of clay was encountered in soil borings at the site. A plastic blue-gray clay and silty clay was encountered from 18.5 to 26 ft deep during the installation of monitoring well TW-A. Finer-grained sediments possibly occur near the river channel beneath the flood protection levee. No soil cores were taken from the direct-push temporary well screens installed along the outside of the levee.

4.3.3 Ground-Water Flow in Alluvial Aquifer

Ground-water levels and flow in the alluvial aquifer are dependent on the stage of the Missouri River. Overall, water levels in the monitoring wells at OU1 respond to changes in the stage of the Missouri River (fig. 4-17). Water levels in well TW-G and well BW-01 closely follow the Missouri River hydrograph. The close relation between water levels in well TW-G and stage of the Missouri River is expected because this well is less than 30 ft from the riverbank. The close relation between water levels in bedrock well BW-01 and the stage of the Missouri River is because this well is open to a confined aquifer system, which, unlike the unconfined alluvial aquifer, responds rapidly to pressure changes caused by fluctuations in the stage of the river. The relation between water level in the alluvial aquifer and river stage is less well defined with increasing distance from the river. Water-level fluctuations in well TW-C (424 ft from well TW-G) are more attenuated than those in well TW-G. Water-level fluctuations in well TW-A (607 ft from well TW-G) respond to long-term river stage fluctuations but do not respond to short-term river stage fluctuations.

The direction of ground-water flow in the alluvial aquifer at OU1 also depends on the stage of the Missouri River. This is illustrated in a series of potentiometric-surface maps of the alluvial aquifer at OU1 from January through June 2001. During periods of low river stage in January and April 2001, ground-water flow was from the Front Street building northeast toward the boat ramp (fig. 4-18 and

fig. 4-19). The gradient in the area between monitoring wells TW-A and TW-C is steep because the alluvial materials are less permeable in this area than in the area north of monitoring well TW-C, as verified by grain-size data. As the river stage increases, the overall gradient between monitoring wells TW-A and TW-G decreases. For example, on January 23, 2001, the hydraulic head difference between monitoring wells TW-A and TW-G was 6.79 ft, and the 7-day average stage of the Missouri River at Hermann, Missouri, prior to January 23 was 3.86 ft. The hydraulic head difference between monitoring wells TW-A and TW-G decreased to 3.99 ft on April 11 when the 7-day stage of the average Missouri River increased to 15.57 ft. The water level in monitoring TW-G rose 10.67 ft between January 23 and April 11, whereas the water level in monitoring well TW-A rose only 7.87 ft (table B-3 Appendix B). A series of potentiometric surface maps of the alluvial aquifer at OU1 from September 1999 through March 2002 is given in Appendix E.

During periods of high stage of the Missouri River, as on June 12, 2001, ground-water flow in the alluvial aquifer is nearly perpendicular to the Missouri River and stagnates as a ground-water trough develops in vicinity of monitoring wells TW-C and TW-E (fig. 4-20). During high river stages, ground-water flow is toward the trough from the south and the north. The gradients are small, as indicated by the less than 0.3 ft of hydraulic head difference between monitoring wells TW-C and TW-G and less than 1 ft of hydraulic head difference between TW-A and TW-C. Of the 295 days of complete water-level record between March 16, 2001 and April 1, 2002, the gradient was reversed (water level in well TW-G was higher than the water level in well TW-C) for 69 days, or 23 percent of the time.

The rate of ground-water flow is a function of the hydraulic gradient, aquifer porosity, and hydraulic conductivity of the aquifer (see section 3.2). The rate at which ground water moves through the alluvial aquifer at OU1 was calculated in two steps along a hypothesized flow path from monitoring wells TW-A to TW-C and then from well TW-C to well TW-G. Average gradients were calculated using the hourly water-level data from the pressure transducers. For the 325 days of complete hourly record for wells TW-A and TW-C, which are 183 ft apart, the average gradient between these wells was 0.027 ft/ft. For the 295 days of complete hourly record for wells TW-C and TW-G, the average gradient between these wells, which are 424 ft apart, was about 0.001 ft/ft. Using an effective porosity of 0.33 and hydraulic conductivity range of 10 to 22 ft/d from slug tests in wells TW-A, TW-C, and TW-G (Appendix D), the average linear ground-water velocity from well TW-C to TW-G ranges from 0.03 to 0.07 ft/d (table 4-3). The average linear ground-water velocity from well TW-A to well TW-C is 0.8 to 1.8 ft/d (table 4-3). If these average linear velocities are correct, then the time for ground water to travel from well TW-A to TW-C is about 102 to 223 days. Because of the shallow

gradient and occasional reversals in gradient, the average travel time for ground water to flow from well TW-C to well TW-G is about 17 to 38 years. These calculations are based on assumptions that the aquifer is homogeneous, preferential flow through more permeable beds does not occur, and no reverse flow occurs from wells TW-G to TW-C during high river stage (flow assumed zero during these periods). The last assumption is made because at high river stages when flow is reversed, wells TW-G and TW-C do not lie on the same flow path.

A second estimate of ground-water velocity and travel time was made that ignores all data during the 69 days of high river stage. Rather than assuming zero flow occurs during periods of high river stage, only data for the 226 days when flow was toward the river was considered, thereby yielding the maximum possible average velocity of ground-water flow in the alluvial aquifer to the Missouri River. For this estimate, the average gradient between wells TW-A and TW-C remained the same at 0.027 ft/ft, and the average gradient between wells TW-C and TW-G was about 0.002 ft/ft. Using the same values of hydraulic conductivity and porosity, the average linear ground-water velocity from well TW-C to TW-G is 0.06 to 0.13 ft/d (table 4-3), and the average travel time for ground water to flow from well TW-C to well TW-G is about 9 to 19 years. These calculations demonstrate that even under the least conservative conditions, the rate of ground-water flow from the Front Street site to the Missouri River is small and the travel time is years to decades.

Table 4-3. Estimates of average linear ground-water velocity in the alluvial aquifer and travel time between indicated wells.

Average gradient	Hydraulic conductivity determined from slug tests	Effective porosity (assumed) ¹	Calculated average linear ground-water velocity	Estimated travel time
0.027 (well TW-A to TW-C)	10 to 22 feet per day	0.33	0.82 to 1.80 feet per day	102 – 223 days (well TW-A to TW-C)
0.001 (well TW-C to TW-G)	10 to 22 feet per day	0.33	0.03 to 0.07 foot per day	16.6 - 38.3 years (well TW-C to TW-G)
0.002 (well TW-C to TW-G) using only water-level data that indicate a gradient toward the Missouri River	10 to 22 feet per day	0.33	0.06 to 0.13 foot per day	8.9 - 19.4 years (well TW-C to TW-G)

¹ Todd (1980).

For the period from March 16, 2001 through April 01, 2001 in which hourly water-level measurements were made in monitoring wells at OU1, the mean daily discharge of the Missouri River at Hermann was slightly below average. This was determined by comparing the daily mean discharge of the Missouri River at Hermann for each day of hourly water-level measurements to the daily mean discharge for each calendar day for the period of record (1928 through 2000). Results of this comparison indicate that the Missouri River discharge during the March 16, 2001, through April 01, 2002, period was above the daily mean discharge on 122 days (32 percent of the time) and below the daily mean discharge on 260 days (68 percent of the time). Although the daily mean discharge was below the period of record daily mean 68 percent of the time, the average difference between the daily mean and period of record daily mean discharge was only 1,300 ft³/s. The results indicate that during the period that hourly water-level measurements were made in the monitoring wells, the Missouri River was generally at lower than average flow. This means that the gradients used in the travel time calculations in table 4-3, which are affected by the Missouri River stage, probably are slightly greater than average, which results in slightly shorter than average calculated travel times for the period of record. However, given the uncertainty in the calculations, the estimated travel times are not unrealistic.

4.4 Nature and Extent of Contamination at Operable Unit 1

4.4.1 Contaminant Sources

The MDNR and USEPA learned during interviews with former employees of NHMC and other businesses that operated at the Front Street building that PCE primarily was used at the site between the mid-1950's and 1972. The primary source of the PCE contamination appears to be waste PCE that was dumped on the ground or washed out of doors on the south side of the building. These wastes likely accumulated or ponded in low areas along the south side of the building and the south side of Front Street near a concrete retaining wall (fig. 4-1).

PCE apparently was not dumped in the sanitary sewer system or other drains at OU1. Sanitary waste from the building flows west into the sanitary sewer beneath Cottonwood Street. This sewer line is accessible upstream and downstream from the Front Street building through manholes, but the sewer line was not sampled at these locations. During the reconnaissance of the building, a capped steel pipe, possibly a floor drain, was discovered in Phase II (fig. 4-1). A 4-in. diameter PVC drainpipe was uncovered by the USEPA along the southeast side of the building while they were excavating cell 25 in 2000 (fig. 4-7 and fig. 4-1). This pipe was about 12-in. deep and ran north beneath the building footing to an unknown location. The pipe extended for about 10 ft from the building and was not seen

in the south side of cell 25. The pipe contained a small quantity of water sufficient for the collection of a sample for the portable GC. Analysis of this sample (sample OU1-CELL 25 PVC, table OU1-3) yielded estimated concentrations of PCE (457.5 µg/L), TCE (64.5 µg/L), and cis-DCE (35.5 µg/L). The contamination in the water could have been the result of recent rainfall infiltrating through contaminated soil and collecting in the pipe or from residual contamination from PCE wastes that may have been discharged into the pipe from an unknown source inside the building.

4.4.2 Soil and Unconsolidated Alluvial Deposits

This section describes the results of environmental sampling of soils (unconsolidated sediment) at 144 locations at OU1. Soil samples from OU1 were analyzed using a portable GC and laboratory methods. About 90 percent of the samples at OU1 were analyzed by use of the portable GC. Although comparable to laboratory values, the results obtained using the portable GC are listed as estimated concentrations. These data are sufficient to allow for characterization of the lateral and vertical extent of PCE contamination in soils at OU1. In the following discussion, the concentrations of PCE in soils are compared to the USEPA Preliminary Remediation Goals (PRGs) for residential use (5,700 µg/kg) and industrial use (19,000 µg/kg) and the removal action limit of 57,000 µg/kg.

4.4.2.1 Tetrachloroethene (PCE) and other VOCs

Substantial PCE contamination was found in soil samples at OU1. Concentrations of PCE were detected at 128 of the 144 soil sample locations at OU1 (fig. 4-21). The largest PCE concentrations (as large as 6,200,000 µg/kg) were detected in about a 4,000-ft² area beneath the southeastern part of the Front Street building and south of the building along Front Street (fig. 4-21). The largest PCE concentration at OU1 was detected in a laboratory sample (sample OU1-EPA-CELL 05, table OU1-4) from a depth of 4.0 ft during the excavation of cell 5 on the south side of Front Street. A nearby soil sample analyzed by the portable GC contained an estimated PCE concentration of 2,205,000 µg/kg (table OU1-5) The east one-third of cell 5 was excavated to 8.0 ft deep so the soil associated with this sample was removed; however, a sample from the floor of the excavation (8 ft deep) in the southeast corner of cell 5 (location OU1-CELL 05) contained PCE at a concentration estimated to be between 553,800 and 1,211,600 µg/kg (table OU1-5), indicating that substantial PCE contamination remained in this area after the removal action was completed.

Results of the sampling indicate PCE concentrations at 15 of the 16 soil sampling locations beneath the current Front Street building exceeded the USEPA residential use PRG of 5,700 µg/kg (fig. 4-21). Nine of the 15 locations had PCE concentrations exceeding the industrial use PRG of 19,000 µg/kg.

Concentrations of PCE at most sampling locations between Front Street and the southeast part the building and in the vicinity of USEPA cell 5 also exceeded the residential use and industrial use PRGs (fig. 4-21).

Concentrations of PCE exceeded 57,000 $\mu\text{g}/\text{kg}$ at 6 locations beneath the building (G52, G53, G54, G61, G63, and G64) and 12 locations along and beneath Front Street south of the building (USGS borings G05, G06, G07, G12, G65, and G65B; and USEPA borings P-05, P-22, P-24, P-25, P-26, and P-28). The “OU1-“ prefix for location numbers have been removed in this discussion to aid in readability. The detection of large concentrations of PCE along Front Street confirms statements made by former employees that PCE was dumped and washed out of doors on the south side of the building. The absence of substantial PCE contamination in soils further east along Front Street and east of the building indicates that PCE dumped or washed out of the building probably accumulated in depressions near the building and did not migrate farther east than the former drainage ditch that was present beneath the concrete pad (fig. 4-21). The data indicate that PCE contamination is not present above the USEPA residential use PRG in soils west or north of the building, or in soils east of the loading dock. A detailed description of the distribution of PCE in soils south of the Front Street building is provided below.

PCE Contamination in source area(s) south of the Front Street building

Concentrations of PCE at OU1 vary substantially with depth. PCE concentrations are largest at shallow depths near locations where PCE was probably dumped (source areas). Based on accounts from former employees and the locations of the maximum PCE concentrations detected in soil samples from the site, two probable PCE source areas exist along the south side of the Front Street building. One source area is in the vicinity of removal action cell 5 (soil borings EPA-P05 and G12) and the second is adjacent to the building in the vicinity of removal action cell 25 and soil borings G65 and G65B (fig. 4-21). Concentrations of PCE in soil samples within these probable source areas were large (typically more than 570,000 $\mu\text{g}/\text{kg}$) at depths less than 5 ft and generally decreased with depth (fig. 4-22). As the distance from probable source areas increases, the PCE concentrations typically decreased and the depth of the peak concentration increased. At almost all locations, PCE concentrations decreased substantially below about 20 ft where the alluvium become sandy and is continuously saturated. As PCE migrates vertically through the soil, it will disperse and the area of soil contamination will widen with increasing depth although the actual concentrations may decrease. Boreholes drilled outside of these “source areas” then would tend to have smaller PCE concentrations

at the surface but have an increased PCE concentration at some depth as the boreholes begin to encounter the dispersed PCE from the source area.

A photograph taken while cell 5 was being excavated near boreholes EPA-P05 and G12 shows soil stained black with PCE and other hydrocarbons (fig. 4-23). The stained soil near the land surface is consistent with statements by former employees of NHMC that wash water from the building drained to a low area on the south side of Front Street, which was gravel until about 1968. Front Street was improved and re-graded by the early 1970's as evidenced by about 1 ft of clean gravel fill on top of the PCE-contaminated gravelly soils in the photograph. Soils at about 4 ft below land surface were stained along the entire 32-ft length of the cell 5 excavation, extending about 3 to 5 ft from the south wall. A laboratory sample of stained soil from the southeastern part of the trench (OU1-EPA-CELL 05) at 4 ft deep contained the largest PCE concentration detected at the site (6,200,000 µg/kg, table OU1-4). Soil samples from nearby boreholes (EPA-P-05 and G12) also contained large PCE concentrations. Concentrations of PCE in a 0-2 ft deep composite sample from boring EPA-P-05 (inside cell 5 and within 10 ft of the location shown in fig. 4-23) contained 914,000 µg/kg PCE (table OU1-6). Concentrations of PCE in borehole EPA-P-05 decreased to 690,000 and 49,300 µg/kg in samples from 2-4 ft and 6-7.5 ft. Concentrations of PCE in borehole G12 (drilled along the north edge of cell 5) increased from an estimated 6,130 µg/kg at 6 ft deep to 5,139,050 µg/kg at 10 ft (fig. 4-22, table OU1-5). PCE was detected at a concentration of 2,200,000 µg/kg in a laboratory sample from borehole G12 at a depth of 8.5 ft (fig. 4-22, table OU1-4). Soils from land surface to 6 ft deep at location G12 were removed during the excavation of cell 5.

The second probable source area, or extension of the source area described above, is adjacent to the Front Street building in the vicinity of borings G-65 and G-65B (fig. 4-21). These two borings were drilled through clean soil replaced after the excavation of cell 25. Concentrations of PCE in samples from these boreholes generally decreased with increasing depth (fig. 4-22). The largest PCE concentration detected in this area (estimated at 1,871,900 µg/kg) was in a sample collected from a depth of 6.0 ft in boring G65B (fig. 4-22, table OU1-5). This sample was collected immediately below the bottom of the clean backfill placed in the cell 25 excavation. A strong PCE odor was emanating from a dry, powdery, sandy-silt at 13.5-13.9 ft deep in borehole G65 and from a damp, sandy-silt at 10.25-11.0 ft in nearby borehole RSH1 (fig. 4-21). Concentrations of PCE in nearby boring G52 (inside the building about 20 ft north of G65B) increased steadily from about 1,000 µg/kg at 2.0 ft deep to an estimated 1,300,000 µg/kg at 16.0 ft deep, then decreased to less than 100 µg/kg below about 28 ft deep (fig. 4-22). The PCE concentration then increased to about 3,400 µg/kg in a

sample from a medium sand at 29.6 ft immediately above the bedrock (table OU1-5). A similar double peak pattern of PCE was observed in boring G54, which is also inside the building and about 31 ft northwest of boring G65B (fig. 4-21). Concentrations of PCE in samples from boring G54 peak at about 340,000 $\mu\text{g}/\text{kg}$ at 16.0 ft deep and at about 240,000 $\mu\text{g}/\text{kg}$ at about 26 ft deep. A slight increase from 850 $\mu\text{g}/\text{kg}$ at 28 ft to 5,000 $\mu\text{g}/\text{kg}$ at 29 ft (coarse sand) was observed at this location. The increase in the PCE concentrations with depth in borings G52 and G54 indicates that these boreholes are near, but not within, a probable PCE source area.

Vertical profiles of PCE, TCE, and cis-DCE for all borings drilled during 2001 and 2002, including those listed above, are shown on plate 2. Data from the boreholes indicate a typical pattern of PCE concentrations peaking between 5 and 20 ft deep in boreholes not close to either of the two probable source areas. No soil samples were collected beneath the middle part of Front Street because of the presence of buried utilities. The concentrations of PCE detected in boreholes along the north and south sides of the street probably also are present beneath the street.

Volume and mass of PCE in Contaminated Soil

A series of shaded contour maps was made to assist in determining the volume of PCE contaminated soils and mass of PCE in soils at OU1. The maps were constructed from all soil data from OU1, including from samples within the excavated USEPA removal action cells. The contours were constructed by use of a linear least-squares triangular irregular network routine in the Geographic Information System ArcInfo™. Contours were constructed for each 2-ft depth interval from the surface to 28 30 ft deep (Appendix A). The estimated volumes of contaminated soil and mass of PCE were calculated for each 2-ft interval. The maps indicate that soil along Front Street south of the building contain PCE concentrations greater than the 57,000 $\mu\text{g}/\text{kg}$ USEPA removal limit to a depth of 26 ft. The aerial extent of contamination tends to increase with increasing depth and is greatest at the 14- to 16-ft depth interval. The estimated mass of PCE and volumes of soil containing more than 19,000 $\mu\text{g}/\text{kg}$ PCE and 57,000 $\mu\text{g}/\text{kg}$ PCE by depth interval are listed in table OU1-7. The total volume of soil containing PCE concentrations greater than 19,000 $\mu\text{g}/\text{kg}$ is estimated to be 5,259 yd^3 . The mass of PCE contained in those soils is 1,938 kg or about 309 gal. The volume of soil containing concentrations of PCE greater than 57,000 $\mu\text{g}/\text{kg}$ is smaller, about 3,577 yd^3 , but the estimated PCE mass is similar (1,872 kg) or about 299 gal. The distribution of contaminants such as PCE in soil generally is neither linear nor well mixed. Contaminant distributions typically increase nearly exponentially near the source. Because the algorithm used to generate the contour maps used a linear function, the estimated volumes of contaminated soil and mass of PCE present probably are

overestimated. The calculations do indicate, however, that a substantial mass of PCE is present in soils at OU1. This mass will be a continued source of PCE to the environment.

Concentrations of TCE, cis-DCE, trans-DCE, and VC in soil samples from OU1 were much smaller than PCE concentrations. Remedial efforts that remove PCE from soils and ground water, also will remove TCE, cis-DCE, trans-DCE, and VC. For example, 20 of the 75 soil samples analyzed by the laboratory contained PCE concentrations greater than the residential PRG of 5,700 µg/kg (table OU1-4). Of these 20 samples, the residential PRG for TCE (2,800 µg/kg) was exceeded in only 4 of the samples, and the residential PRG for cis-DCE (43,000 µg/kg) was exceeded in 1 sample. The residential PRG for VC (150 µg/kg) was exceeded in 2 of the 20 samples.

4.4.2.2 Trace Elements

A total of 36 samples were analyzed for the metals listed in table OU1-8. Background sites in the New Haven area were not sampled for metals, and background concentrations of metals were approximated from those sediments deposited on the Missouri River flood plain during the 1993 flood (Schalk and others, 1998). The background concentration of each metal was calculated as the mean concentration plus three standard deviations of the concentrations listed in Schalk and others (1998). Concentrations of metals in alluvial deposits can be variable because of the varied mineralogy of the alluvial deposits. Sands usually have smaller concentrations of most metals, whereas finer-grained deposits, such as silts and clays, usually have larger concentrations of metals. Exceptions occur, especially when sands have a large quantity of iron-oxide coatings or where they contain minerals such as feldspar, zircon, and mica that are known to be enriched in trace elements. Concentrations of metals in soils also were compared to the USEPA residential and industrial use PRGs.

Concentrations of metals in most samples were less than background except for cadmium (Cd, 6 samples), copper (Cu, 2 samples), lead (Pb, 17 samples), mercury (Hg, 16 samples), and zinc (Zn, 7 samples). Except for Pb (fig. 4-24), none of the concentrations exceeded the USEPA residential or industrial use PRGs. Concentrations of Pb ranged from 5.6 µg/kg in a sample from boring G01 to 11,600 µg/kg in a sample from monitoring well borehole TW-F at 1.5 to 2.0 ft deep (table OU1-8). Concentrations of Pb exceeded the residential PRG of 400 µg/kg in three samples: EPA-P-81 at 0 to 2 ft deep (615 µg/kg), G59 at 2.0 to 2.5 ft deep (607 µg/kg), and TW-F at 1.5 to 2.0 ft deep (966 and 11,600 µg/kg). None of these samples contained large PCE concentrations, indicating that the occurrence of high concentrations of Pb in soils is not related directly to the use and disposal of PCE

at OU1. The large difference in the Pb concentration in the split sample from borehole TW-F (966 and 11,600 µg/kg) indicates that the Pb probably is present as discrete Pb-rich particles or actual fragments of elemental Pb. An X-ray diffraction analysis was not done on this sample to determine the origin of the high Pb concentration.

The elevated Pb concentrations in several soil samples is expected considering the many industrial uses of the site and the widespread historic use of Pb in plumbing, solders, gasoline, building materials, fishing weights, and paint. Borehole TW-F is in the vacant lot across (west) Cottonwood Street from the Front Street building (fig. 4-24). According to local historians, this lot was the site of a flour mill that burned down in the early 1900's. The geologic log from borehole TW-F indicated that as much as 20 ft of fill, including bricks, old asphalt, and nails, were present in this area. Although Pb-based dyes were used in the production of tents in New Haven during the 1950's through the 1970's, these dyes are an unlikely source of Pb because the fabric dyeing took place at the Orchard Street facility more than 0.5 mi east of OU1.

The number and distribution of soil samples analyzed for metals is sufficient to characterize the extent and magnitude of metals contamination outside the building; however, only one sample from a location inside the building (G59) was analyzed for metals. This one sample contained a Pb concentration (607 µg/kg) larger than the residential use PRG (table OU1-8). Lead is extremely insoluble in water and it tends to migrate in the environment only as a particulate. Lead in soils beneath the building is not expected to migrate; however, additional sampling of soils beneath the building may be needed if these soils are to be disturbed or removed.

4.4.2.3 Semivolatile Organic Compounds

Forty soil samples from OU1 were analyzed for 109 SVOCs (table OU1-9). Thirteen of the 40 samples contained detectable concentrations of 1 or more SVOCs with a total of 21 SVOCs being detected. The concentrations of SVOCs detected ranged from 58 µg/kg in a sample from borehole RNH4 (0 to 2 ft deep) to about 275,000 µg/kg in a sample from 1.5 to 2.0 ft deep in borehole TW-F (table OU1-9). All of the SVOCs detected were polynuclear aromatic hydrocarbons (PAHs), such as pyrene (12 detections); fluoranthene (10 detections), and benzo(b)-fluoranthene, benzo(g,h,i)-perylene, and chrysene (8 detections). Concentrations of five compounds exceeded the USEPA residential use PRGs, and concentrations of three compounds exceeded the USEPA industrial use PRGs (table OU1-9). The sample from the 1.5 ft to 2.0 ft depth interval in monitoring well borehole TW-F contained benzo(a)anthracene (11,000 µg/kg), benzo(a)pyrene (16,000 µg/kg), and

benzo(b)fluoranthene (15,000 µg/kg) above the residential and industrial use PRGs. This is the same sample that contained the large Pb concentrations (966 and 11,600 µg/kg) above the residential and industrial use PRGs.

Locations containing detectable concentrations of SVOCs are scattered across the site with no apparent spatial pattern (fig. 4-25). Common sources of the detected SVOCs are road asphalt and roofing tar; however, locations containing SVOCs did not correlate well with areas covered by asphalt. For example, SVOCs were not detected in samples from several locations along Front Street south of the building, whereas they were detected in samples from gravel areas near the loading dock and north of the building (EPA-P-81 and RNH4, fig. 4-25). Nearly all SVOCs were detected in shallow (less than or equal to 2 ft deep) soils. In boreholes where samples were collected at several depths, the sample from the shallowest depth (typically less than or equal to 2.0 ft deep) contained much larger SVOC concentrations than samples from greater depths. Of the 13 samples containing detectable SVOCs, only 2 samples were from depths greater than 2 ft (table OU1-9).

The distribution of locations at which SVOCs were detected does not correlate well with the distribution of locations at which PCE was detected. Some, if not most, of the SVOC concentrations are caused by industrial practices not directly related to PCE use at the site. No SVOCs were detected in either sample collected from inside the building (locations G-50 and G-59).

4.4.2.4 Pesticides and Polychlorinated Biphenyls (PCBs)

Thirty-six soil samples were submitted for analyses of PCBs and organochlorine pesticides (table OU1-10). None of the samples contained detectable concentrations of PCBs. Eight of the samples contained detectable concentrations of one or more of eight organochlorine pesticides. The largest concentrations of pesticides were detected in the 0-2 ft deep sample from location EPA-P-25 (1,010 µg/kg of total pesticides) and in the 1.5-2.0 ft deep sample from borehole TW-F (130 µg/kg 4,4'-DDT). Sample EPA-P-25 (0 to 2 ft) contained estimated concentrations of 4,4'-DDT (120 µg/kg), 4,4'-DDD (690 µg/kg), and 4,4'-DDE (200 µg/kg). No concentration of the organochlorine pesticides exceeded the USEPA residential use or industrial use PRGs. Several samples contained concentrations of pesticides that could not be confirmed on the secondary analytical column and their concentrations are marked with a "Col" in table OU1-10. The occurrence of the organochlorine pesticides is consistent with their environmental persistence and widespread use during the 1940's through the early 1970's and is not directly related to PCE disposal at the site. Only one sample from inside the building (location G-59 at 2.0 to 2.5 ft deep) was analyzed for PCBs and organochlorine

pesticides. This sample contained 4,4'-DDT and 4,4'-DDD at concentrations of 8.8 µg/kg and 5.9 µg/kg (table OU1-10). Additional characterization of these compounds may be needed if future activities disturb the soil beneath the building.

4.4.3 Ground Water in the Alluvial Aquifer

The following discussion focuses on the general geochemistry and distribution of PCE and other VOCs in the alluvial aquifer at OU1. Because the fate of PCE in ground-water systems depends in part on the geochemical conditions in the aquifer, a discussion of the general geochemistry is presented first to provide a framework in which to understand the distribution of PCE and its degradation products.

4.4.3.1 General Ground-Water geochemistry

Ground water in the Missouri River alluvial aquifer at OU1 generally has near neutral pH values (6.80 to 7.52) and moderately large specific conductance values [450 to 1,429 µS/cm (microsiemens per centimeter at 25 degrees Celsius); table OU1-11]. Calcium (Ca) and magnesium (Mg) are the predominant cations and bicarbonate (HCO₃) and chloride (Cl) are the predominant anions (table OU1-12). Samples were analyzed for inorganic chemical constituents during November 1999 and November 2000. No samples from temporary wells were analyzed for inorganic constituents. Concentrations of inorganic chemical constituents in samples from monitoring wells at OU1 were compared to concentrations in samples from monitoring wells installed by the USGS in the Missouri River alluvial aquifer that determined background water quality in the alluvial aquifer about 40 mi downstream from New Haven (Kleeschulte, 1993). Overall, specific conductance values and concentrations of sodium (Na) and Cl in monitoring wells in the alluvial aquifer at OU1 were substantially larger than the background values and concentrations (table OU1-12). The elevated concentrations of Na (31 to 95 mg/L) and Cl (57 to 234 mg/L) probably are related to the storage of road salt at the city utilities shed (fig. 4-1) immediately west of well TW-A. Road salt has been stored (only partially covered) at this location for more than 25 years.

Ground water in the alluvial aquifer generally is anaerobic with DO concentrations less than 0.5 mg/L (fig. 4-26). Dissolved oxygen concentrations ranged from less than the detection limit of 0.05 mg/L in several samples to a maximum of 2.71 mg/L in a sample from temporary well GP28 at 20-24 ft deep (table OU1-11). Overall, specific conductance and pH values and concentrations of DO in samples from temporary well screens were comparable to those in samples from monitoring wells; therefore, the two data sets are treated as one (fig. 4-26). Ground-water samples from some locations, such as

monitoring well TW-A and temporary wells G-50 and G-67, had large estimated concentrations of Fe^{2+} (more than 5 mg/L) indicating that Fe-reducing conditions exist at some locations.

Concentrations of Fe^{2+} were measured sporadically and not available for many locations. During sampling at several locations, the odor of H_2S gas was detected as sample containers were filled, indicating the presence of SO_4 -reducing conditions. Attempts were made to measure H_2S concentrations using a field colorimetric test kit with a detection level of 0.1 mg/L; however, no H_2S was detected using the kit even though a strong H_2S smell could be detected emanating from some water samples.

In addition to affecting the water levels and potentiometric gradient in the alluvial aquifer, changes in stage of the Missouri River also can affect the basic geochemistry of ground water in the alluvial aquifer. For example, specific conductance values in monitoring well TW-G are positively correlated with water level and increase as the depth to water increases (fig. 4-27). Concentrations of pH and DO exhibit a strong negative correlation with water level and increase as the depth to water level decreases. The decrease in specific conductance of nearly 25 percent during early 2001 indicates the mixing of fresh water from the river with alluvial ground water in the vicinity of well TW-G during periods of higher stage of the Missouri River.

An estimate of the probable terminal electron accepting processes in the alluvial aquifer was made using measured concentrations of DO, Fe^{2+} , dissolved Fe, and NO_3 , and noting the presence of an H_2S gas odor. The criteria used were based on those used in the USEPA Natural Attenuation Screening Protocol (U.S. Environmental Protection Agency, 1998). Concentrations of DO larger than 0.5 mg/L generally indicate aerobic conditions that are not favorable for the reductive dechlorination of PCE. Concentrations of dissolved NO_3 less than 1 mg/L were considered to indicate that NO_3 -reducing conditions may be present, which generally are not conducive to the reductive dechlorination of PCE. Concentrations of Fe^{2+} larger than 1 mg/L indicated that Fe-reduction was a likely terminal electron accepting process, and the presence of a detectable odor of H_2S gas was inferred to indicate the possible presence of SO_4 -reducing conditions. Iron- and SO_4 -reducing conditions are favorable for the reductive dechlorination of PCE. Overall, Fe- and SO_4 -reducing conditions persist in the alluvial aquifer at monitoring well TW-A. Conditions in the vicinity of well TW-B generally appear to be aerobic or minimally NO_3 -reducing as samples from this well contained NO_3 concentrations (1.66 and 1.69 mg/L, table OU1-12) larger than 1 mg/L. Strongly reducing conditions generally were not identified in water samples from well TW-C where DO concentrations ranged from less than 0.05 to 1.0 mg/L and Fe^{2+} concentrations, when measured, were less than 0.3 mg/L (table OU1-11). Conditions at monitoring well TW-G were highly variable and appeared to fluctuate between mildly

aerobic to SO₄-reducing. A thorough characterization of the terminal electron accepting conditions within the alluvial aquifer would require more frequent measurements of the above constituents and perhaps dissolved hydrogen.

4.4.3.2 Trace Elements

Concentrations of trace elements in samples from the alluvial aquifer generally were within the background limits except for boron (B), Fe, and Mn (table OU1-12). Concentrations of B were larger than background in samples from wells TW-A (150 µg/L), TW-C (160 and 211 µg/L), and TW-G (160 µg/L). Boron cannot be attributed to any known industrial activities at the site or in the vicinity, but may be related to variations in mineralogy within the alluvial aquifer. The large concentrations of Fe and Mn probably are related to the presence of naturally occurring Fe and Mn oxides within the alluvial deposits and the reduction of Fe and Mn within the alluvial aquifer at OU1. Reduced forms of Fe and Mn are much more soluble than their oxides. Concentrations of both of these constituents exceeded the USEPA secondary drinking water standard in ground-water samples (300 µg/L for Fe and 50 µg/L for Mn). Samples from well TW-B contained small concentrations of Fe (6 and 22 µg/L) and NO₃ concentrations greater than 1.0 mg/L, indicating the absence of Fe-reducing conditions in the alluvial aquifer in the vicinity of this well.

4.4.3.3 PCE and Other Volatile Organic Compounds

Concentrations of PCE were detected in 22 of the 28 ground-water sampling locations in alluvial aquifer in the vicinity of OU1 (fig. 4-10). Thirteen of the 14 locations having PCE concentrations above the maximum contaminant level (MCL) of 5 µg/L were in the vicinity of the Front Street building or downgradient from the building near the boat ramp (fig. 4-28). Sample results indicate that a plume of PCE greater than the MCL of 5 µg/L extends from Front Street south of the Front Street building northeast to the boat ramp (fig. 4-28). The plume is about 600 ft long and less than about 300 ft wide. The distance the plume extends in the alluvial deposits beneath the Missouri River is not known. An apparently isolated area of PCE contamination (20 µg/L) above the MCL also was detected east of the site at temporary well screen location GP01. The largest PCE concentrations were detected in ground-water samples from beneath the east part of the Front Street building at temporary well screen locations G67 (11,000 µg/L), G50 (6,600 µg/L), and G51 (6,100 µg/L; table OU1-13). Large PCE concentrations also were detected about 400 ft downgradient (northeast) from the building near the boat ramp in samples from monitoring well TW-G (less than 1 to 670 µg/L) and temporary well screen locations GP22 (less than 130 to 1,100 µg/L) and GP28 (5.9 to 340 µg/L). PCE was not

detected upgradient (south) from the site in monitoring well TW-A or west of the site in monitoring well TW-F and temporary well screen locations GP09 or GP19 (fig. 4-28).

Concentrations of PCE varied with depth, but consistently increased with depth at locations beneath the building. An example is the 100-fold increase in PCE concentrations at temporary well screen location G50 from 66 µg/L at 23.7 to 27.7 ft deep to 6,600 µg/L at 27.6 to 31.08 ft deep (table OU1-13). At downgradient locations, PCE concentrations mostly decreased with depth. For example, PCE concentrations in the 2- to 24-ft deep and 31- to 35-ft depth intervals at location GP28 were larger than 200 µg/L but decreased to 5.9 µg/L in the 42- to 46-ft depth interval (table OU1-13). At location GP22, PCE concentrations decreased from 1,100 µg/L in the 22.5- to 26.5-ft depth interval to less than 130 µg/L in the 34.5- to 38.5-ft depth interval (table OU1-13).

A plume of TCE concentrations above the MCL of 5 µg/L generally coincides with the PCE plume (fig. 4-29). Concentrations of TCE exceed the MCL at 10 locations. Similar to PCE, the largest TCE concentrations were detected in water samples from beneath the building at temporary well screen installations G67 (5,500 µg/L), G50 (4,700 µg/L), and G51 (2,500 µg/L; table OU1-13). Smaller TCE concentrations were detected downgradient from the site at temporary well screen locations GP22 (less than 130 µg/L to 650 µg/L), GP28 (1.1 to 88 µg/L), and monitoring well TW-G (less than 1 µg/L to 280 µg/L). The vertical distribution of TCE generally followed that of PCE with TCE concentrations increasing with depth beneath the building and concentrations decreasing with depth at downgradient locations near the boat ramp (fig. 4-29).

Concentrations of cis-DCE exceeded the MCL of 70 µg/L at eight locations. The plume of cis-DCE contamination above the MCL is similar in size to the plumes of PCE and TCE contamination (fig. 4-30). Concentrations of cis-DCE also varied with depth but not as consistently as detected in the PCE and TCE concentrations. For example, concentrations of cis-DCE at temporary well screen location G50 increased with depth from 22 µg/L (23.7 to 27.7 ft deep) to 3,100 µg/L (27.6 to 31.08 ft deep); however, cis-DCE concentrations at location G67 (3,100 and 2,800 µg/L) were similar at both sample depths (table OU1-13). Despite concentrations of PCE and TCE below detection in the deep interval (34.5 to 38.5 ft deep) at temporary well screen location GP22, concentrations of cis-DCE were large (3,100 µg/L), indicating substantial biodegradation of PCE and TCE at this location and depth.

Concentrations of VC were larger than the MCL of 2 µg/L at five locations. The plume of VC contamination extends from the southeastern part of the Front Street building to the Missouri River near the boat ramp (fig. 4-31). The footprint of the VC plume is smaller than that of the PCE plume.

Unlike PCE, TCE, and cis-DCE, where the maximum concentrations were detected beneath the Front Street building, the maximum VC concentrations were detected downgradient from the site near the Missouri River boat ramp in monitoring well TW-G (41 to 630 µg/L) and temporary well screen installations GP22 (6.2 J to 410 µg/L) and GP28 (2.1 J µg/L to an estimated 57 µg/L; table OU1-13).

Small concentrations of toluene (0.12 to 1.8 µg/L) were detected in 15 samples (table OU1-13). Twelve of the 15 detections were from temporary well screen installation samples. Benzene was detected in five samples from three locations (temporary well screen locations G50 and GP25 and monitoring well TW-C). Except for the large benzene concentrations (160 and 340 µg/L) detected in the samples from G50, benzene concentrations were less than the MCL of 5 µg/L (table OU1-13). The large benzene concentrations detected at location G50 probably are related to the presence of petroleum hydrocarbons at this location. Water purged from both temporary well screen sample depths at location G50 had a strong “hydrocarbon odor” and an oily sheen was present on the water surface in the 5-gal bucket used to collect purge water. Location G50 is within 25 ft of the filled concrete sump used as an oil bath by Transportation Specialists Inc. This was the only location at OU1 where petroleum hydrocarbon contamination was encountered in the subsurface.

4.4.4 Bedrock Aquifer

Concentrations of PCE were detected in the bedrock aquifer in monitoring wells BW-00 (1.3 to 1.4 µg/L), BW-00A (0.86 J µg/L), BW-01 (4.9 to 22.8 µg/L), and BW-01A (0.40 J to 2.7 µg/L). No other VOCs were detected in samples from the bedrock monitoring wells. Monitoring well BW-00, BW-00A, and BW-01A are less than 175 ft deep and open to the Cotter or Jefferson City Dolomites (Appendix C). Monitoring well BW-01 is 385 ft deep and open to the lower part of the Jefferson City Dolomite and most of the Roubidoux Formation. Water samples collected from the open borehole during the drilling of monitoring well BW-01 had PCE concentrations (16.4 and 22.8 µg/L) larger than those in water samples collected after the well was completed (4.9 to 6.2 µg/L, table OU1-13), indicating that the interval(s) contributing the largest PCE concentrations to the open borehole were grouted or cased out when the well casing was set. The vertical profile of PCE concentrations in samples collected every 5 ft during the drilling of the borehole indicates that the largest estimated PCE concentrations were detected in two discrete zones – a zone between about 35 and 100 ft deep and a zone between about 275 and 340 ft deep (fig. 4-32). Both wells BW-01 and BW-01A are open to part of the two PCE bearing zones but not the complete thickness of either zone.

Bedrock monitoring wells at OU1 are near the end of the ground-water flow paths (Missouri River is the regional ground-water drain) in the Cotter and Jefferson City Dolomite and Roubidoux Formation (fig. 1-17). The distribution of PCE concentrations in the bedrock at location BW-01 and detection of PCE concentrations greater than 200 ug/L in the bedrock upgradient and south of public-supply well W2 in monitoring well BW-02 (fig. 4-32) indicates that much of the PCE contamination in the deep monitoring wells at OU1 probably is from a source south of public-supply well W2.

4.4.5 Missouri River surface-water and sediment

No PCE contamination was detected in surface-water or bed-sediment samples collected from the bottom of the Missouri River in the vicinity of OU1 (table OU1-14). Sample locations were selected on the assumption that PCE-contaminated ground water was discharging into the base of the riverbed along the south side of the river. Because PCE was not detected in the water or bed-sediment samples, the flux of contaminants probably is not large enough to be detectable given the large volume of dilution occurring in the river. Small concentrations of toluene (0.48 J to 0.98 J $\mu\text{g/L}$) in water samples from all 10 locations may indicate trace contamination from gasoline either in the river or from the engines of the boat used to collect the samples. Toluene also was detected (19 and 270 $\mu\text{g/kg}$) in two bed-sediment samples. Because elevated Pb had been detected in soils at OU1, Pb was analyzed in four of the bed-sediment samples. The Pb concentrations (5 to 14.5 $\mu\text{g/kg}$) were within acceptable background concentrations for the New Haven area.

4.5 Contaminant Fate and Transport at Operable Unit 1

The following discussion focuses on factors that affect the fate (persistence) and transport (migration) of PCE and its degradation products in soil and ground water at OU1. This discussion builds on the general principles discussed in section 3.2.

4.5.1 Soils

An examination of the vertical profile of PCE in soils at OU1 indicates that, in general, PCE concentrations in the upper 2 to 3 ft of soil are smaller than those at deeper depths (plate 2). This relation is true even in the suspected source areas in the vicinity of boreholes G12 and G65 (fig. 4-22). The most likely mechanism for PCE introduction into the soils at OU1 was by disposal directly on the land surface. Volatilization from the shallow subsurface probably is an important loss mechanism within the upper few feet of soil at the site but is not important at depth.

One of the primary loss or degradation mechanisms for PCE in the subsurface is biodegradation by reductive dechlorination as described in section 3.2. Microbial reactions occur throughout the subsurface if the soil contains sufficient moisture, a reduced organic carbon source, and appropriate electron acceptors. Historically, PCE was used to remove petroleum-based lubricating oils from aluminum tent poles at OU1. Industrial oils are reduced sources of organic carbon and, under favorable conditions, microorganisms can readily couple the oxidization of these oils with the reduction of PCE. The reductive dechlorination of PCE requires anaerobic conditions (preferably Fe- or SO₄-reducing), which can exist as “microenvironments” within the pores in unsaturated soils at OU1. A plot of the molar fraction of PCE to TCE and to cis-DCE plus VC in 73 soil samples from OU1 analyzed by the laboratory indicates that some biodegradation of PCE is occurring (fig. 4-33). Most VOC distributions plot near the lower right vertex (area of minimal biodegradation) of the diagram indicating that more than 75 percent of the total chlorinated ethenes (PCE plus TCE plus cis-DCE plus VC) are present as PCE. Minimal biodegradation of PCE is occurring in these soils. Two of the soil samples (G11 at 22.0 ft deep and G64 at 16.0 ft deep) plot near the lower left vertex (area of substantial biodegradation) where PCE comprises less than 25 percent of the total chlorinated ethenes. Substantial biodegradation of PCE has occurred in these samples (fig. 4-33). An additional six samples plot along the lower axis of the plot indicating some biodegradation of PCE has occurred. In these samples, PCE comprises about 20 percent (G16 at 1.5-2.0 ft deep and G51 at 24.0 ft deep) to about 67 percent (G02 at 6.0 to 6.5 ft deep) of the total chlorinated ethenes detected in these samples. Except the 6.0-to 6.5-ft deep sample from location G02 in which TCE composed about 25 percent of the total chlorinated ethenes, TCE was a minor component in the soil samples. Most of the soil samples where some biodegradation of PCE has occurred were from relatively shallow (less than 5 ft) depths (fig. 4-33). Most of the chlorinated ethenes present in soil at the site are still present as PCE 30 to 50 years after release, which indicates that microbial degradation of PCE in unsaturated soil at OU1 is a slow process. Trace quantities of TCE and cis-DCE up to a few percent may be present in commercial-grade PCE; however, the assessment of the degree of reductive dechlorination of PCE is based on the assumption that TCE, cis-DCE, and VC were not used as products at the site and their presence is the result of reductive dechlorination of PCE.

The detection of large PCE concentrations (greater than 57,000 µg/kg) beneath the building floor, especially beneath the older parts of the building, such as at location G61, is unexpected because of the absence of floor drains and substantial cracks or joints in the floor. PCE possibly was dumped on the ground in these areas in the late 1950's and 1960's before building additions were placed over them. A clue to the origin of PCE contamination in these areas may be in the vertical distribution of

PCE. At most locations beneath the building that contain more than 57,000 $\mu\text{g}/\text{kg}$ PCE, the PCE concentrations generally increased with increasing depth, reaching a maximum at depths between 15 and 20 ft, then decreased with further depth (fig. 4-22). This is in contrast to the vertical profiles of PCE near the two probable “source areas” outside the building discussed in section 4.4.2.1, where PCE concentrations generally decreased with increased depth. There are three likely mechanisms that could explain the maximum PCE concentrations that occur between 15 and 20 ft deep in many areas.

1. Locations where PCE concentrations peak at some depth are near but not actually within a “source area” where PCE was introduced to the land surface, but yet they are near enough to intersect PCE dispersed through the soil at depth.
2. A “smearing” effect caused by the water table fluctuating beneath the site.
3. Soils at depths of 15 to 20 ft have a greater affinity for adsorbing PCE (for example, high organic carbon content).

The first mechanism was discussed in section 4.4.2.1 and is thought to explain the large PCE concentrations at depths of 15 to 20 ft in borehole G52 (fig. 4-22). However, large PCE concentrations (greater than 57,000 $\mu\text{g}/\text{kg}$) were detected in soil samples at depths of 15 to 20 ft in boreholes G53 and G64—as much as 75 ft from one of the probable “source areas”. The “smearing” of PCE caused by fluctuating water levels in the alluvial aquifer may explain the increase in PCE concentrations with depth in these samples. The water table beneath the site generally is about 20 ft below the surface, but commonly rises to 10 ft or less during high stages of the Missouri River. When the water table rises, dissolved PCE is carried upward into silts in the alluvium that generally are not saturated. This dissolved PCE will partition or adsorb to the silts according to the organic carbon content of the material as described in section 3.2. When the water table falls, the PCE adsorbed to these silts remains. This adsorbed PCE would generally be protected from degradation processes, as is evident in figure 4-33. Repeated cycles of rising and falling water levels over the 30- to 50-year period since PCE was used at the site could serve to move and adsorb a measurable quantity of PCE onto soils not associated with direct contamination from the surface. This process probably caused the increase in PCE concentrations at depths between 10 and 20 ft observed in boreholes beneath the Front Street building. This mechanism also could explain the detection of PCE in soils further from the building such as at monitoring well TW-D (more than 200 ft north of the Front Street building). Concentrations of PCE were small (less than 25 $\mu\text{g}/\text{kg}$) in samples from monitoring well TW-D but

tended to increase with increasing depth (plate 2). This monitoring well is located at a private residence with no historic connection to the Front Street facility.

The possibility that soils at the 15-to 20-ft depth have a greater affinity for adsorbing PCE is unlikely because there appears to be no substantial increase in the organic carbon content in soil at these depths as compared to shallow depths (table OU1-2). In fact, a marked decrease exists in organic carbon content in the soil samples below about 20 ft deep, which would cause these soils to have a smaller affinity for adsorbing PCE.

In summary, although volatilization and some reductive dechlorination of PCE in soils at OU1 have occurred, these processes appear to be slow. Because substantial PCE concentrations remain in soils at the site after 30 to 50 years, mechanisms for PCE loss from soil at the site will not remove a substantial mass of PCE from the soils for decades to come.

4.5.2 Ground Water

The detection of substantial concentrations of TCE, cis-DCE, and VC in ground-water samples from OU1 indicates that biodegradation of PCE is occurring in the alluvial aquifer. The biodegradation of PCE is consistent with the presence of Fe- and SO₄-reducing conditions in the alluvial aquifer discussed in section 4.4.3.1. The amount of biodegradation of PCE depends on the location and depth within the alluvial aquifer. For example, minimal biodegradation is occurring at upgradient locations near the probable source areas along Front Street (such as locations GP13 and G52) where PCE comprises more than 75 percent of the total chlorinated ethenes in ground-water samples (fig. 4-34). Exceptions are samples from nearby locations GP12 and G65B where PCE comprised less than 40 percent of the total chlorinated ethenes. Samples from locations GP12 and G65B also contained much smaller concentrations of PCE and its degradation products than samples from locations GP13 and G52 (fig. 4-28 through fig. 4-31). The amount of biodegradation tended to increase with increasing distance downgradient with PCE comprising less than 40 percent of the total chlorinated ethenes in samples from location G50 and only about 32 to 48 percent of the total chlorinated ethenes in samples from location G67 (fig. 4-34). Samples from G50 and G67 contain some of the largest PCE concentrations detected in ground water at OU1 (66 to 11,000 µg/L, table OU1-13). PCE comprised about 18 to 67 percent of the total chlorinated ethenes in samples from monitoring well TW-C (fig. 4-34), which is near the edge of the PCE plume and about 125 ft downgradient of the probable source area. Substantial biodegradation of PCE is occurring further downgradient near the Missouri River where, on average, PCE comprises less than 10 percent of the total chlorinated ethenes in several

samples from monitoring well TW-G and in samples from the deep intervals at locations GP22 and GP28 (fig. 4-34).

Little relation exists between the degree of biodegradation and depth at locations beneath the Front Street building. For example, samples collected from both depths at temporary well screen location G50 (23.7-27.7 and 27.6-31.1 ft deep) had similar fractions of PCE (about 37 percent PCE) despite the deeper sample having PCE concentrations 100 times (6,600 µg/L) larger than those detected in the shallow sample (66 µg/L). The deep (32-34 ft deep) sample at location G67 (about 48 percent PCE and 30 percent TCE) plots near the samples from location G50, but the shallow sample (24-28 ft deep) plots near the bottom of the diagram (about 32 percent PCE and 10 percent TCE), indicating proportionately more biodegradation of TCE to cis-DCE at the shallower depth. The substantial amount of biodegradation of PCE and lack of trends with depth at locations G50 and G67, which are only about 100 ft downgradient from the probable sources areas beneath Front Street, may be related to the presence of petroleum hydrocarbons that were detected during the ground-water sampling at location G50. The presence of petroleum hydrocarbons enhances the rate and degree of biodegradation of chlorinated solvents such as PCE because petroleum hydrocarbons provide a source of reduced organic carbon for the bacteria (food), and the presence of the reduced organic carbon drives aerobic degradation processes that consume oxygen and produce the anaerobic conditions required for reductive dechlorination of PCE. The lack of a strong trend of biodegradation with depth beneath the building also may reflect the limited saturated thickness (less than 10 ft thick at the time samples from G50 and G67 were collected) of the alluvium near the building.

Downgradient near the Missouri River, the degree of biodegradation of PCE increases with increasing depth below the water table. For example, samples from temporary well screen locations GP22 and GP28 generally plot along a line trending toward the lower left vertex of figure 4-34 as the sample depth increases. The shallow samples from these locations plot toward the middle part of figure 4-34 with PCE plus TCE composing about 46 percent (GP22, 22.5-26.5 ft deep) to 75 percent (GP28, 20-24 ft deep) of the total chlorinated ethenes. In contrast, the deep samples from locations GP22 (34.5 to 38.5 ft deep) and GP28 (42 to 46 ft deep) plot at the lower left vertex (PCE plus TCE less than 5 percent of the total chlorinated ethenes) indicating near complete biodegradation of PCE and TCE (fig. 4-34). The intermediate depth samples from these locations plot in between the deep and shallow samples (fig. 4-34). A probable cause for the increase in the degree of biodegradation with increasing depth is that the alluvium thickens toward the Missouri River and consequently the saturated thickness increases to more than 25 ft near temporary well screen locations GP22 and GP28 and monitoring well TW-G. The greater the thickness of the saturated zone, the greater the potential to

develop vertical stratification in the concentrations of electron acceptors such as DO, which is carried to the water table by infiltration and diffusion from the land surface.

The distribution of PCE, TCE, cis-DCE, and VC in samples from monitoring well TW-G is variable over time and is affected by the stage of the Missouri River. Samples from TW-G plot along a line trending from about 68 percent cis-DCE plus VC to 100 percent cis-DCE plus VC indicating substantial biodegradation of PCE in the alluvial aquifer at this location (fig. 4-34). The degree of biodegradation generally is related to water-level depth, which is influenced by the stage of the Missouri River. When water level-depths are less than 16 ft, cis-DCE and VC comprise more than 90 percent of the chlorinated ethenes (fig. 4-34). In contrast, in samples collected when water-level depths were greater than 20 ft, cis-DCE and VC comprised less than 90 percent of the chlorinated ethenes. Ground water in the alluvial aquifer between TW-G and the river and beneath the river probably is extremely anaerobic resulting in nearly complete biodegradation of PCE and TCE with a corresponding buildup of cis-DCE and VC. During periods of rising or high river stage when gradients are away from the river, this anaerobic ground water is pushed into the alluvial aquifer in the vicinity of well TW-G. For example, during periods of high river stage between March and June 2001, increases in cis-DCE, Fe^{2+} , VC concentrations corresponded to decreases in PCE and TCE concentrations (fig. 4-35). The relation of VOC distributions with river stage is not simple because dissolved oxygen concentrations increased and the molar concentrations of total chlorinated ethenes nearly doubled in these samples. Monitoring well TW-G has a long open-interval (22 ft to 45 ft deep) and the increase in concentrations of dissolved oxygen, Fe^{2+} , molar concentration of total chlorinated ethenes during this period indicates the mixing of water from various geochemical zones in the alluvial aquifer within the well during periods of high river stage. Evidence for the stratification of contamination and geochemical zones in the alluvial aquifer is the variation in the distribution of PCE and its degradation products with depth in water samples collected at temporary well screen locations GP22 and GP28 (table OU1-13).

Because of interaction with organic carbon in the aquifer matrix, the rate of PCE transport through the alluvial aquifer is estimated to be about 25 to 40 percent (retardation factors of 2.5 to 4.0, table 4-4) of the rate of ground-water movement. These estimates were made using the retardation equation (equation 4) listed in section 3.2, values of K_{oc} listed in table 3-1, an aquifer porosity of 33 percent, and an organic carbon content of 0.1 to 0.2 percent for the saturated alluvium (table OU1-2).

Multiplying the estimated ground-water travel times calculated in table 4-3 by the retardation factor of 2.5 to 4.0 gives travel times of PCE from well TW-C to well TW-G ranging from about 22 to 77 years at a gradient of 0.002 to about 44 to 154 years at a gradient of 0.001. PCE has traveled from the

vicinity of well TW-C to well TW-G in less than about 45 years, indicating that the larger estimated travel times are not realistic. Because of the order-of-magnitude accuracy in the hydraulic conductivity estimates determined from slug tests and the uncertainty in estimating an average hydraulic gradient in the alluvial aquifer, the calculated retardation factors probably are better known and more reliable than the estimates of the average linear ground-water velocity. Based on the above, the shorter estimates for the ground-water travel time from well TW-C to well TW-G listed in table 4-3 of about 9 to 19 years are probably more realistic.

In addition to dissolved concentrations in the ground water, a substantial fraction of PCE is adsorbed onto the aquifer matrix. In the 32-to 34-ft deep interval at temporary well screen location G67, the concentration of PCE in the ground water was 11,000 µg/L (table OU1-13). Using equation 3 in section 3.2 and assuming equilibrium conditions and using 0.1 percent for the organic carbon content of the aquifer and a K_{oc} value for PCE of $10^{2.44}$ (from table 3-1), the PCE concentration in the solid phase in contact with the ground water in the 32-to 34-ft deep interval at location G67 is about 3.0 mg/kg (table 4-5). On a per liter volume basis at this location, about 40 percent of the PCE (3.63 mg) is in the liquid phase and 60 percent (5.45 mg) is adsorbed onto the solid phase (table 4-5). Assuming equilibrium, the calculations indicate that in each cubic foot of aquifer containing a PCE concentration of 11,000 µg/L, the total mass of PCE in the liquid and solid phases would be 103 mg and 154 mg (table 4-5). At temporary well screen location GP22, the maximum estimated mass of PCE in the liquid and solid phases per cubic foot of aquifer at equilibrium are 10 mg and 15 mg (table 4-5).

Estimates of the rate of reductive dechlorination of PCE, TCE, cis-DCE, and VC were made using the USEPA analytical simulation BIOCHLOR (Aziz and others, 2000). BIOCHLOR is a simplified screening-level simulation that assumes uniform geohydrologic conditions in the aquifer, simple ground-water flow, and simple first order biodegradation and adsorption. The simulation was used assuming a hypothetical source area in the saturated zone 10 ft thick and 20 ft wide near the south side of the Front Street building with assumed dissolved concentrations of PCE (50,000 µg/L), TCE (10,000 µg/L), cis-DCE (1,000 µg/L), and non-detectable concentrations of VC. Additional assumptions were an average linear ground-water velocity of 47 ft/yr (feet per year), organic carbon content of 0.1 percent, aquifer porosity of 33 percent, and retardation factors of 4.0 (PCE), 2.5 (TCE), 1.5 (cis-DCE), and 2.0 (VC). Assuming 40 years between the release of PCE into the alluvial aquifer and the collection of ground-water samples at OU1, the estimated half-lives of PCE, TCE, cis-DCE, and VC were adjusted until the simulation closely predicted the measured concentrations detected at temporary well screen location GP22 (520 ft downgradient from the assumed source area). Three separate simulations were made to predict the concentrations of contaminants detected in the shallow (22.5 to 26.5 ft deep), intermediate (26.5 to 30.5 ft deep), and deep (34.5 to 38.5 ft deep) samples at location GP22. Data from the deep (32 to 34 ft deep) interval at location G67 (assumed to be 100 ft downgradient from the assumed source area) also were used to constrain the calculations. A summary of the model input parameters and results is listed in Appendix F. The estimated half-lives of PCE in the alluvial aquifer range from 4.1 years in the shallow simulation to 0.8 year in the deep simulation

(table 4-6). The simulations indicate that in the deeper part of the alluvial aquifer, the reductive dechlorination process nearly stalls at the production of cis-DCE (estimated half-life of 12 years). The simulations also indicate that VC is rapidly degraded (estimated half-lives less than or equal to 0.06 year) in the shallow and intermediate depths, but degraded at a slower rate (estimated half-life of 3.5 years) deeper in the aquifer. Rapid mineralization of VC to carbon dioxide has been shown to occur under Fe-reducing conditions in aquifer sediments (Bradley and Chapelle, 1998). The simulation results are not unique, are used for screening purposes only, and are not intended for assessment of human-health or ecological risks.

4.6 Baseline Risk Assessment for Operable Unit 1

4.6.1 Human-Health Risk Assessment for Operable Unit 1

The MDHSS performed a Human-Health Risk Assessment for OU1 at the Riverfront Site in Summer 2002. A complete assessment of human-health risks associated with OU1 can be found in Baseline Risk Assessment for Operable Unit 1 (OU1)–Front Street, The Riverfront Site, New Haven, Franklin County, Missouri, (Missouri Department of Health and Senior Services, 2003).

The Baseline Risk Assessment evaluated the risks to human health in various hypothetical exposures to contaminated media. MDHSS used soil and ground-water sample results from the investigations discussed in this RI to generate the contaminant levels for the exposure scenarios. All exposure scenarios assumed that no remedial actions or contaminant attenuation would occur at OU1. The Baseline Risk Assessment also identified contaminants and exposure pathways that should be addressed by any future remedial actions. Based on the results of this Baseline Risk Assessment, OU1 poses risks from both the surface soil and ground-water pathways.

The following sections discuss the risks from the contaminated soils at OU1 and from the contaminated ground water at OU1. Tables 4-7 and 4-8 summarize the potentially affected populations, the applicable exposure pathways, and the degree of risk to each population.

Table 4-7. Summary of carcinogenic human-health risks at operable unit OU1.

Population scenario	Exposure pathway	Type of exposure (RI sample results evaluated)	Pathway carcinogenic risk	Total risk for scenario
Future Resident	Ground Water	Drinking Water Ingestion (well water sampling)	1.7×10^{-3}	1.7×10^{-3}
		Dermal Contact (well water sampling)	5.7×10^{-5}	
		Inhalation (well water sampling)	7.1×10^{-6}	
Future Resident	Ground Water	Drinking Water Ingestion (borehole sampling)	1.0×10^{-2}	1.1×10^{-2}
		Dermal Contact (borehole sampling)	6.2×10^{-4}	
		Inhalation (borehole sampling)	7.2×10^{-5}	
Future Resident	Surface Soil	Incidental Ingestion	7.1×10^{-5}	1.2×10^{-4}
		Dermal Contact	2.1×10^{-5}	
		Inhalation	2.9×10^{-5}	
Future Occupational Worker	Ground Water	Drinking Water Ingestion (well water sampling)	3.1×10^{-4}	3.1×10^{-4}
Future Occupational Worker	Ground Water	Drinking Water Ingestion (borehole sampling)	2.3×10^{-3}	2.3×10^{-3}
Current or Future Occupational Worker	Surface Soil	Incidental Ingestion	7.8×10^{-6}	2.9×10^{-5}
		Dermal Contact	9.8×10^{-6}	
		Inhalation	1.1×10^{-5}	
Future Recreational	Surface Soil	Incidental Ingestion	1.2×10^{-5}	2.1×10^{-5}
		Dermal Contact	3.6×10^{-6}	
		Inhalation	5.0×10^{-6}	
Current Trespasser	Surface Soil	Incidental Ingestion	3.0×10^{-6}	5.3×10^{-6}
		Dermal Contact	5.4×10^{-7}	
		Inhalation	1.8×10^{-6}	
Current or Future Construction/Utility Worker	Subsurface Soil	Incidental Ingestion	2.9×10^{-7}	1.1×10^{-6}
		Dermal Contact	1.3×10^{-8}	
		Inhalation	8.4×10^{-7}	
<p>Note 1: USEPA considers a total lifetime cancer risk for a reasonable maximum exposure that exceeds 10^{-4} to be unacceptable. Total excess lifetime cancer risks below 10^{-6} are considered acceptable.</p> <p>Table adapted from the Missouri Department of Health and Senior Services (2003a).</p>				

Table 4-8. Summary of non-carcinogenic human-health risks at operable unit OU1.

Non-Carcinogenic Risks				
Population scenario	Exposure pathway	Type of exposure (RI sample results evaluated)	Pathway non-carcinogenic risk	Total risk for scenario
Future Resident	Groundwater	Drinking Water Ingestion (well water sampling)	11	12
		Dermal Contact (well water sampling)	0.5	
		Inhalation (well water sampling)	0.04	
Future Resident	Groundwater	Drinking Water Ingestion (borehole sampling)	181	192
		Dermal Contact (borehole sampling)	11	
		Inhalation (borehole sampling)	0.8	
Future Occupational Worker	Groundwater	Drinking Water Ingestion (well water sampling)	3	3
Future Occupational Worker	Groundwater	Drinking Water Ingestion (borehole sampling)	51	51
Note: Human health risks may exist when the Total Hazard Index for Non-carcinogenic effects exceeds a value of 1.0.				
Table adapted from MDHSS, 2003a.				

4.6.1.1 Risks from Surface Soils at OU1

There is the potential for substantial carcinogenic risks for current or future occupational workers, future residents, current trespassers, and future recreational visitors from contact with soils at OU1. There is a potential for incidental ingestion of soils, dermal contact with soils, and inhalation of particulate matter or volatiles from soils, which combine to create an unacceptable risk for the future resident scenario. These pathways present carcinogenic risks that are greater than 1×10^{-6} (1 in 1 million). PCE drives the risk for the inhalation pathway, and arsenic and benzo(a)pyrene drive the soil ingestion and dermal contact pathways.

4.6.1.2 Risks from Ground Water Underlying OU1

There is the potential for unacceptable excess carcinogenic risks and adverse non-carcinogenic health effects for future residents and occupational workers who ingest ground water from the contaminated aquifers that underlie OU1. In addition, there is the potential for unacceptable excess carcinogenic risks for future residents from the inhalation of, ingestion of, and dermal

contact with ground-water contaminants while showering. PCE, TCE, VC, and the other breakdown products of these chlorinated solvents are largely responsible for these health risks.

4.6.1.3 Other Pathways at OU1

The sediment and surface water pathways at OU1 were not evaluated as a part of the Baseline Risk Assessment because these pathways did not contain sufficient detections of site-related contaminants. The Baseline Risk Assessment also did not include a qualitative analysis of human exposure to PCE and other volatile organic compounds from vapor seepage into home and building foundations. This exposure pathway could potentially be a completed pathway. However, the basement, building interior, and ambient air sampling results were not available at the time of the publication of the Risk Assessment. Quantitative assessment and risk calculations based on these air sampling results will be conducted by the Missouri Department of Health and Senior Services, when the data become available.

4.6.2 Ecological Risk Assessment for Operable Unit 1

An Ecological Risk Assessment (ERA) was conducted during this RI to evaluate the ecological risks at the Riverfront Site. A complete assessment of the ecological risks for the Riverfront Site can be found in *Ecological Risk Assessment Riverfront Superfund Site, City of New Haven, Franklin County, Missouri*, (Black & Veatch Special Projects Corp., 2002). The methodology used in the ERA was based on, and complied with, the latest guidance described in the *Ecological Risk Assessment Guidance for Superfund: Process for Designing and Conducting Ecological Risk Assessments* (USEPA, 1997).

Based on site conditions and the physical properties of the contaminants at OU1, the ERA considered the direct exposure risks associated with stream sediment and surface water in the Missouri River. In addition, the ERA also evaluated a food chain ingestion model for herbivores. Ecological screening values (ESVs) are contaminant-specific, media-specific concentrations that are used to determine the risk that any particular contaminant might pose to ecological receptors. Concentrations of the chlorinated ethenes PCE, TCE, cis-DCE, trans-DCE, VC, and the volatile hydrocarbons benzene and toluene were compared to ESVs to determine the risk that contaminants in each media might pose to ecological receptors. Benzene and toluene were

included in the ecological assessment because small concentrations of these compounds had been detected in ground-water samples from OU1

Analytical results from Missouri River sediment samples collected near OU1 were compared to the selected ESVs for stream sediment. Toluene was detected in two of the stream sediment samples, but the detected concentrations were well below the ESVs for sediment (table 4-9). Based on this comparison, there are no significant ecological risks presented by sediment sampled in the Missouri River near OU1. It is important to note that the reporting limit for VC was higher than the ESV, so there could be concentrations of this compound between the reporting limit and the ESV.

Analytical results for Missouri River surface water associated with OU1 were compared to the selected ESVs for surface water. Toluene was detected in several of the surface-water samples, but the concentrations were well below the ESVs for surface water (table 4-9). No significant ecological risks are presented by surface water contamination at OU1.

Estimated concentrations of compounds detected by the portable GC in tree-core and fruit samples from OU1 were converted to exposure doses. All seven target compounds were detected in the tree tissue samples at OU1. The estimated average daily doses for the representative mammal and bird species were compared to the wildlife ESVs. Based on these comparisons, none of the target compounds were present at levels that indicate a significant risk to herbivores. The overall conclusion of the ERA was that ecological risks are minimal at OU1 of the Riverfront Site (BVSPC, 2002).

Table 4-9. Summary of laboratory results for the Ecological Risk Assessment at Operable Unit OU1.

[ug/kg, micrograms per kilogram; ug/L, micrograms per liter; PCE, tetrachloroethene; TCE, trichloroethene; cis-DCE, cis-1,2-dichloroethene; trans-DCE, trans-1,2-dichloroethene; VC, vinyl chloride; nd, not detected

Target Compound	Number of samples	Number of detections	Minimum detected	Maximum detected	Ecological Screening Value (ESV) ¹
Stream-bed Sediment (Missouri River)					
PCE	8	0	nd	nd	195.83 ug/kg
TCE	8	0	nd	nd	179.56 ug/kg
cis-DCE	8	0	nd	nd	208.94 ug/kg
trans-DCE	8	0	nd	nd	208.94 ug/kg
VC	8	0	nd	nd	2 ug/kg
Benzene	8	0	nd	nd	57 ug/kg
Toluene	8	2	19 ug/kg	270 ug/kg	670 ug/kg
Surface Water (Missouri River)					
PCE	10	0	nd	nd	8.9 ug/L
TCE	10	0	nd	nd	75 ug/L
cis-DCE	10	0	nd	nd	310 ug/L
trans-DCE	10	0	nd	nd	310 ug/L
VC	10	0	nd	nd	9.2 ug/L
Benzene	10	0	nd	nd	46 ug/L
Toluene	10	10	0.48 ug/L	0.98 ug/L	130 ug/L

¹ All results listed above are from *Ecological Risk Assessment Riverfront Superfund Site, City of New Haven, Franklin County, Missouri*, (BVSPC, 2002).

4.7 Summary and Conclusions for Operable Unit 1

Results of the investigations at OU1 indicate the presence of substantial PCE contamination in soils at the site and in ground water in the alluvial aquifer beneath and downgradient (northeast) of the site. Concentrations of PCE were detected in 128 of 144 soil sample locations at the site. The largest PCE concentrations (as large as 6,200,000 $\mu\text{g}/\text{kg}$) were detected in soils beneath the southeast part of the Front Street building and beneath Front Street immediately south of the building. PCE waste was washed out loading doors on the south side of the building. PCE concentrations at most soil sampling locations beneath the building and south of the building exceeded the USEPA residential use PRG of 5,700 $\mu\text{g}/\text{kg}$. PCE concentrations at about one-half the soil sampling locations beneath the building and at many locations south of the building also exceeded the industrial use PRG of 19,000 $\mu\text{g}/\text{kg}$. Concentrations of PCE generally increased with increasing depth; peak concentrations were at depths below 6 ft. The maximum lateral extent of soil contamination at the site occurred between 14 and 16 ft deep. More than 5,000 yd^3 of PCE-contaminated soil, containing an estimated PCE mass of 1,938 kg or about 309 gallons, are present in soil at OU1. No PCE contamination above the residential use PRG was detected in soils north of the building, east of the loading dock on the east side of the building, or on a vacant lot west of the building. Substantial degradation of PCE is not occurring in soils at the site, and the PCE in the soils will continue to be a source of contamination to ground water for decades.

A selected number of soil samples from the site also were analyzed for metals, pesticides, PCBs, and SVOCs. Concentrations of Pb exceeded the residential use PRG of 400 mg/kg in eight shallow (less than 2 ft deep) soil samples collected from three locations (one beneath the building, one north of the building, and one on the vacant lot west of the building). Concentrations of one or more SVOCs (all PAHs) exceeded the residential use PRGs at seven locations with the largest concentrations detected in a sample from the vacant lot west of the building. No pesticides or PCBs were detected above the residential use PRGs in any soil samples from the site.

Large concentrations of PCE and its microbial degradation products TCE, cis-DCE, and VC were detected in ground-water samples from the alluvial aquifer at OU1 and downgradient (northeast) of the site near the Missouri River. PCE was detected in 22 of the 28 ground-water sampling locations in the alluvial aquifer, and concentrations exceeded the MCL of 5 $\mu\text{g}/\text{L}$ at 13 locations. The largest PCE concentrations (as large as 11,000 $\mu\text{g}/\text{L}$) were detected in ground-water samples collected beneath the northeast corner of the Front Street building (location G67). Samples from this location also contained large concentrations of TCE (5,500 $\mu\text{g}/\text{L}$) and cis-DCE (3,000 $\mu\text{g}/\text{L}$).

Based on results of ground-water sampling and PCE concentrations detected in tree-core samples (which are thought to mimic the ground-water concentrations), a plume of PCE-contaminated ground water extends from near the south side of the Front Street building toward the northeast beneath several residences to the Missouri River about 600 ft away. Because of the small hydraulic gradient in the alluvial aquifer, the rate of PCE migration through the alluvial aquifer to the Missouri River is small, and travel times are on the order of 9 to 19 years.

Conditions within the alluvial aquifer generally are conducive to the biodegradation of PCE to TCE, cis-DCE, and VC. Substantial microbial degradation of PCE is occurring as the PCE migrates from source areas along the south side of the Front Street building to the Missouri River. Near the source areas, PCE composes more than 75 percent of the total chlorinated ethenes, whereas downgradient near the Missouri River, PCE composes less than 10 percent of the chlorinated ethenes with cis-DCE and VC being the predominant compounds detected. Estimates of the half-life of PCE in the alluvial aquifer range from 0.8 to 4.1 years. Although substantial microbial degradation of PCE is occurring in the alluvial aquifer, the degradation appears to generally stall at the production of cis-DCE (estimated half-life of 12 years). Because of the relatively slow rate of advection through the alluvial aquifer and generally slow degradation rate, concentrations of PCE and its microbial degradation products in the alluvial aquifer likely will remain above USEPA MCLs for decades.

Baseline Risk Assessment scenarios for OU1 found that there are human-health risks associated with the contamination at OU1. The potential for future exposure to ground water and surface soil contamination at OU1 was found to pose significant health risks. Ground water underlying OU1 poses unacceptable excess carcinogenic and non-carcinogenic health risks for future residents who might inhale, ingest, or have dermal contact with contaminated ground water. In addition, future occupational workers are also susceptible to unacceptable excess carcinogenic and non-carcinogenic health risks from ingestion of the contaminated ground water. Contact with soils at OU1 poses unacceptable excess carcinogenic health risks to future residents, current and future occupational workers, current trespassers, and future recreational visitors.

The Ecological Risk Assessment indicated that contamination at OU1 is of minimal risk to environmental receptors. Toluene was detected in the surface water and stream sediment in the Missouri River near OU1; but the concentrations of the contaminants were not large enough to present a significant risk to ecological receptors. VOCs were found to be present in vegetation at OU1, but the concentrations were not high enough to pose an unacceptable risk to herbivores.

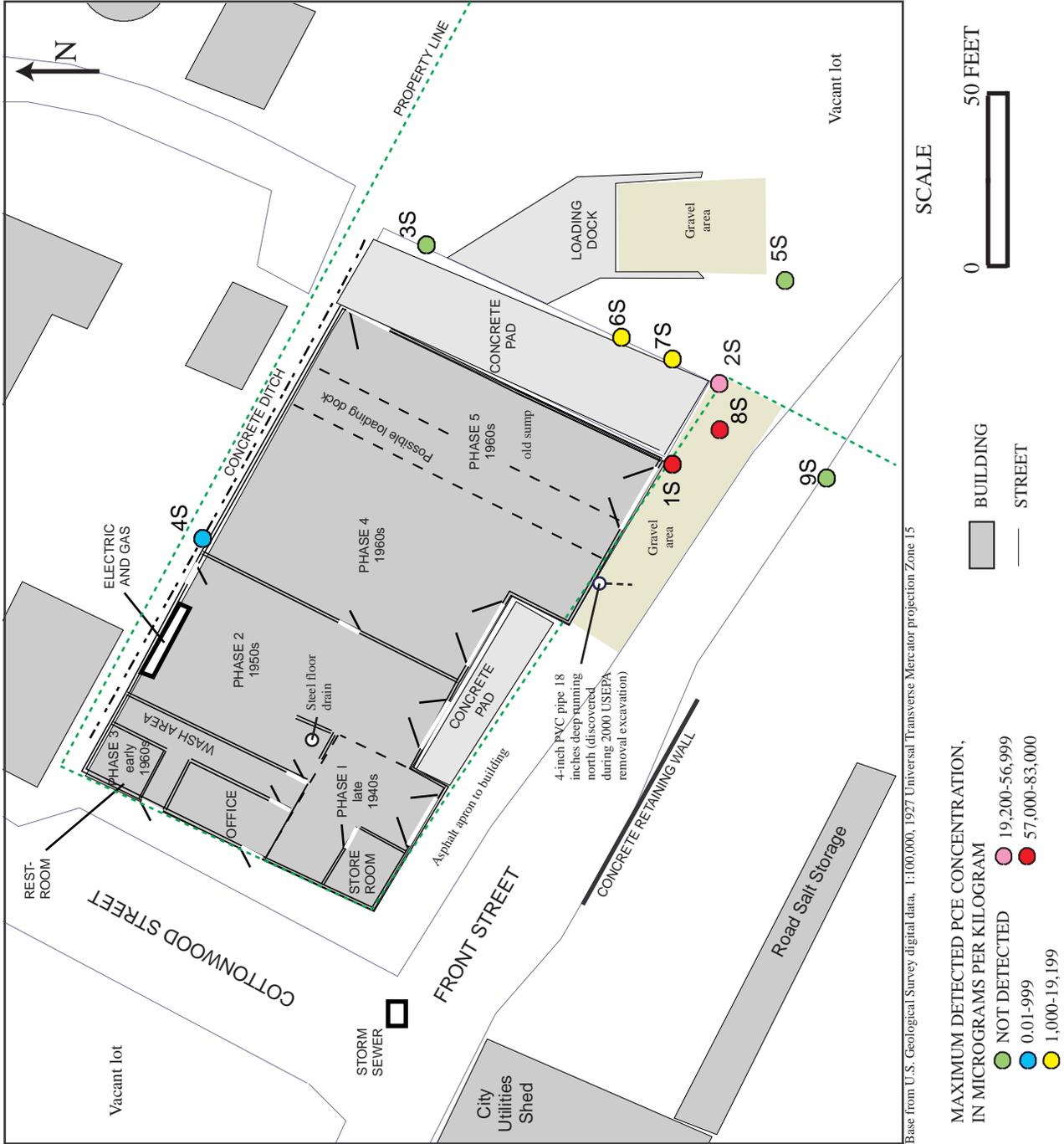
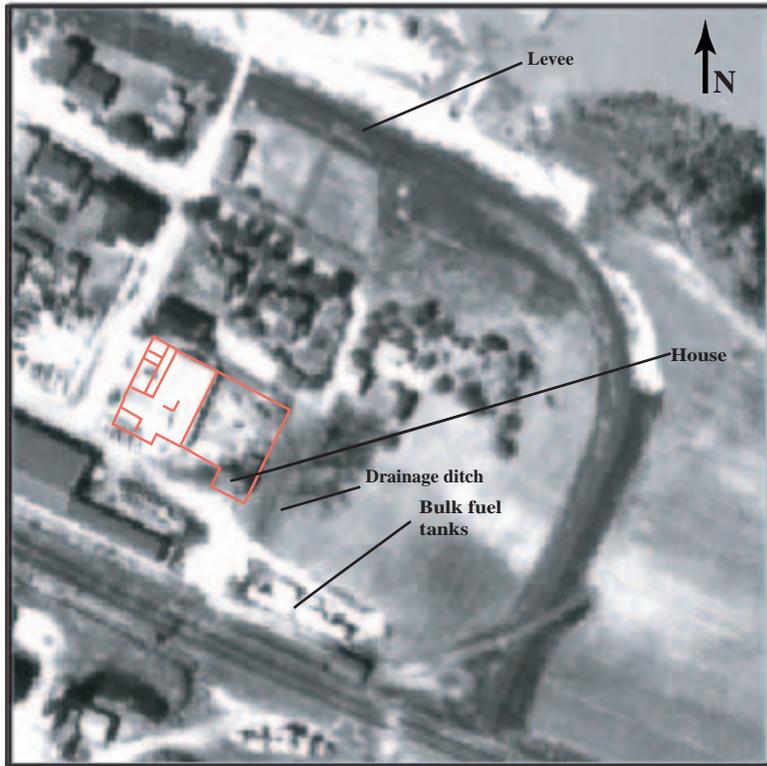


Figure 4-1. Soil borings and maximum tetrachloroethene (PCE) concentrations detected during the Expanded Site Investigation (ESI) at the Front Street Site (Operable Unit 1), November 1993 [data from the Jacobs Engineering Group Inc. (1994)].



1958

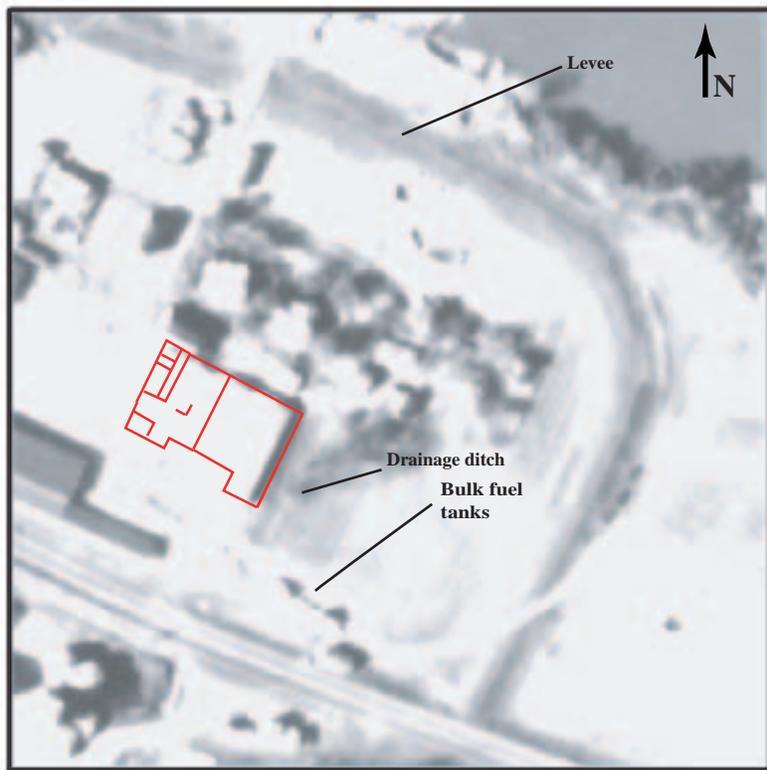
U.S. Army Corps of Engineers, Kansas City District



1960

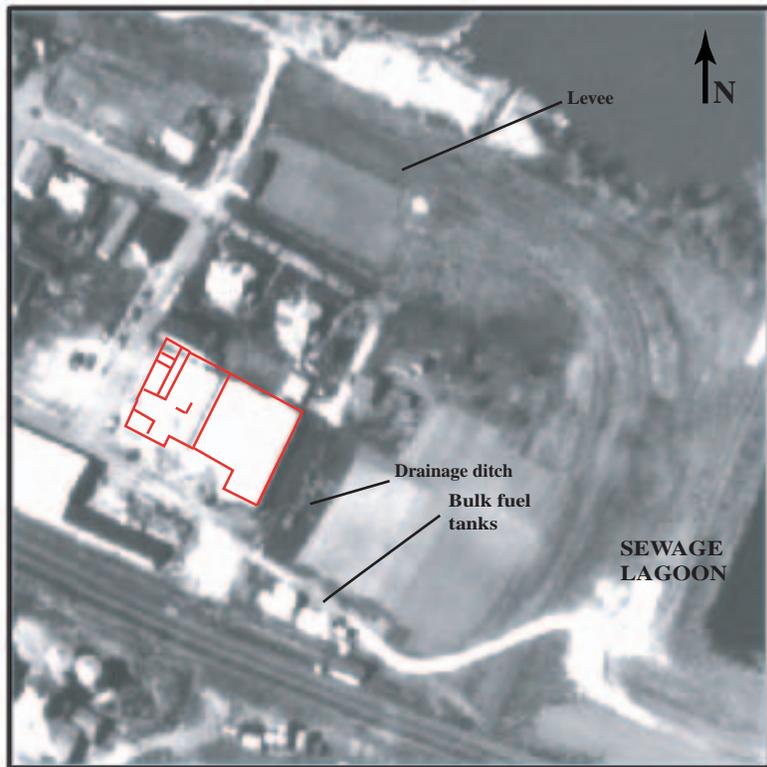
U.S. Army Corps of Engineers, Kansas City District

Figure 4-2. Aerial photograph of Operable Unit 1 (OU1) during 1958 and 1960.



1968

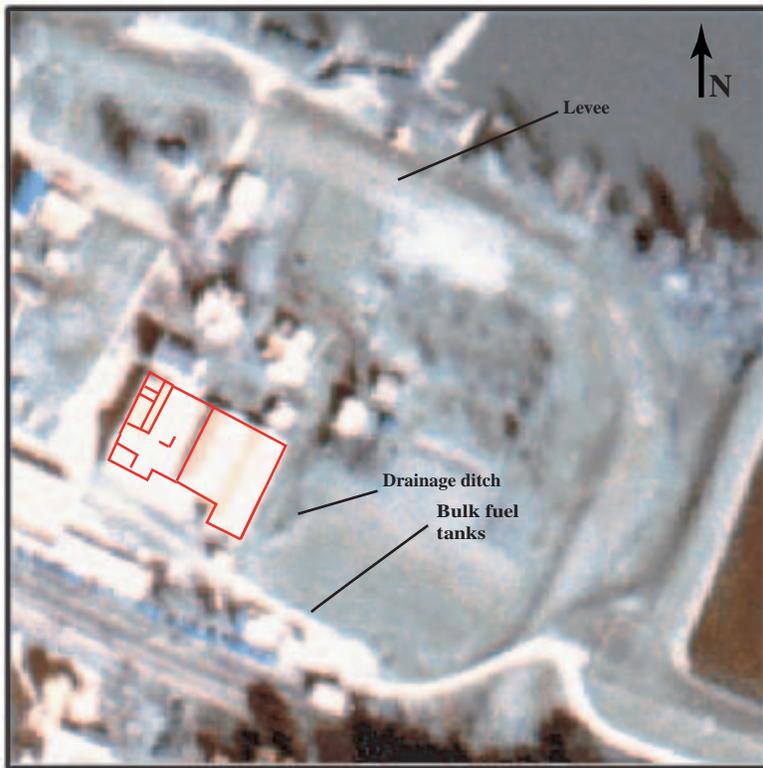
U.S. Army Corps of Engineers, Kansas City District



1970

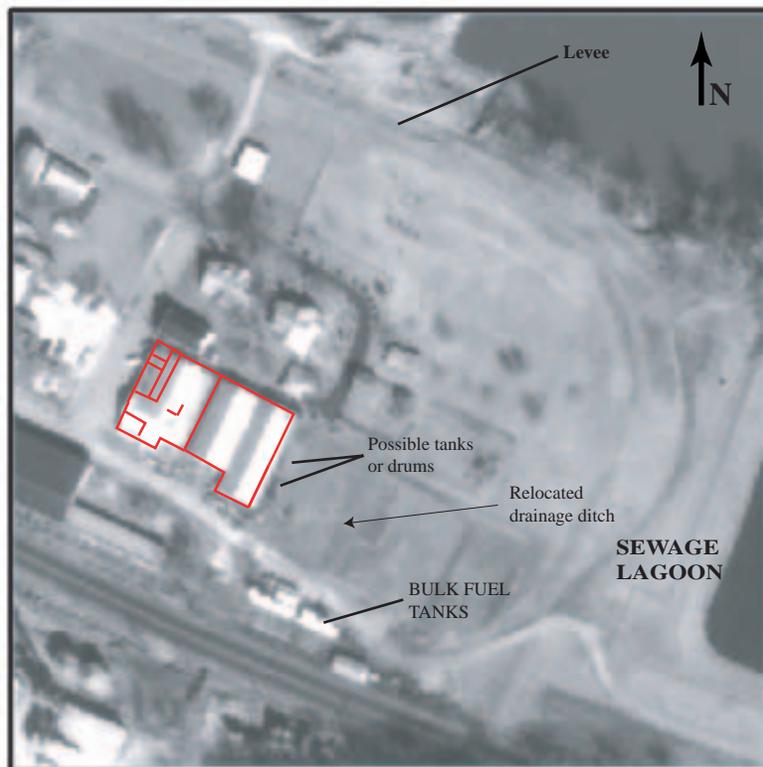
U.S. Geological Survey

Figure 4-3. Aerial photograph of Operable Unit 1 (OU1) during 1968 and 1970.



1979

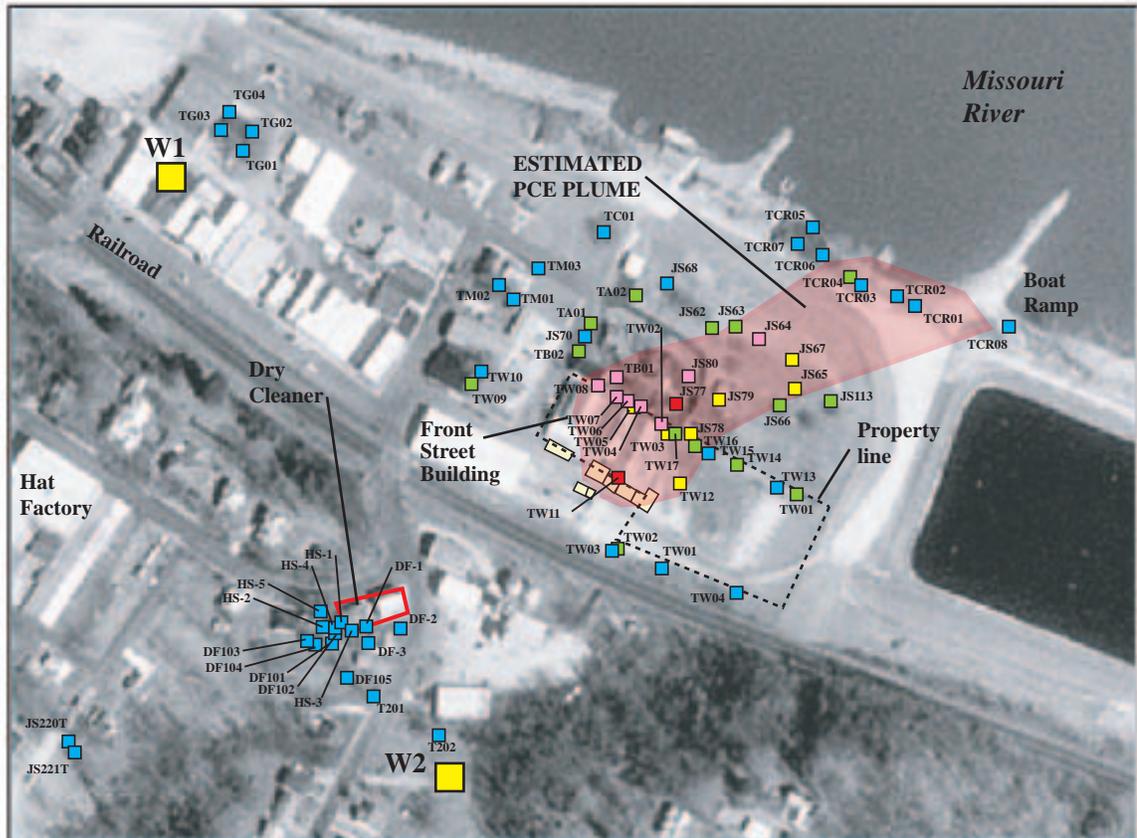
U.S. Geological Survey



1986

U.S. Army Corps of Engineers, Kansas City District

Figure 4-4. Aerial photograph of Operable Unit 1 (OU1) during 1979 and 1986



Base from U.S. Geological Survey digital orthophoto, 1:24,000, 1927 Universal Transverse Mercator projection Zone 15

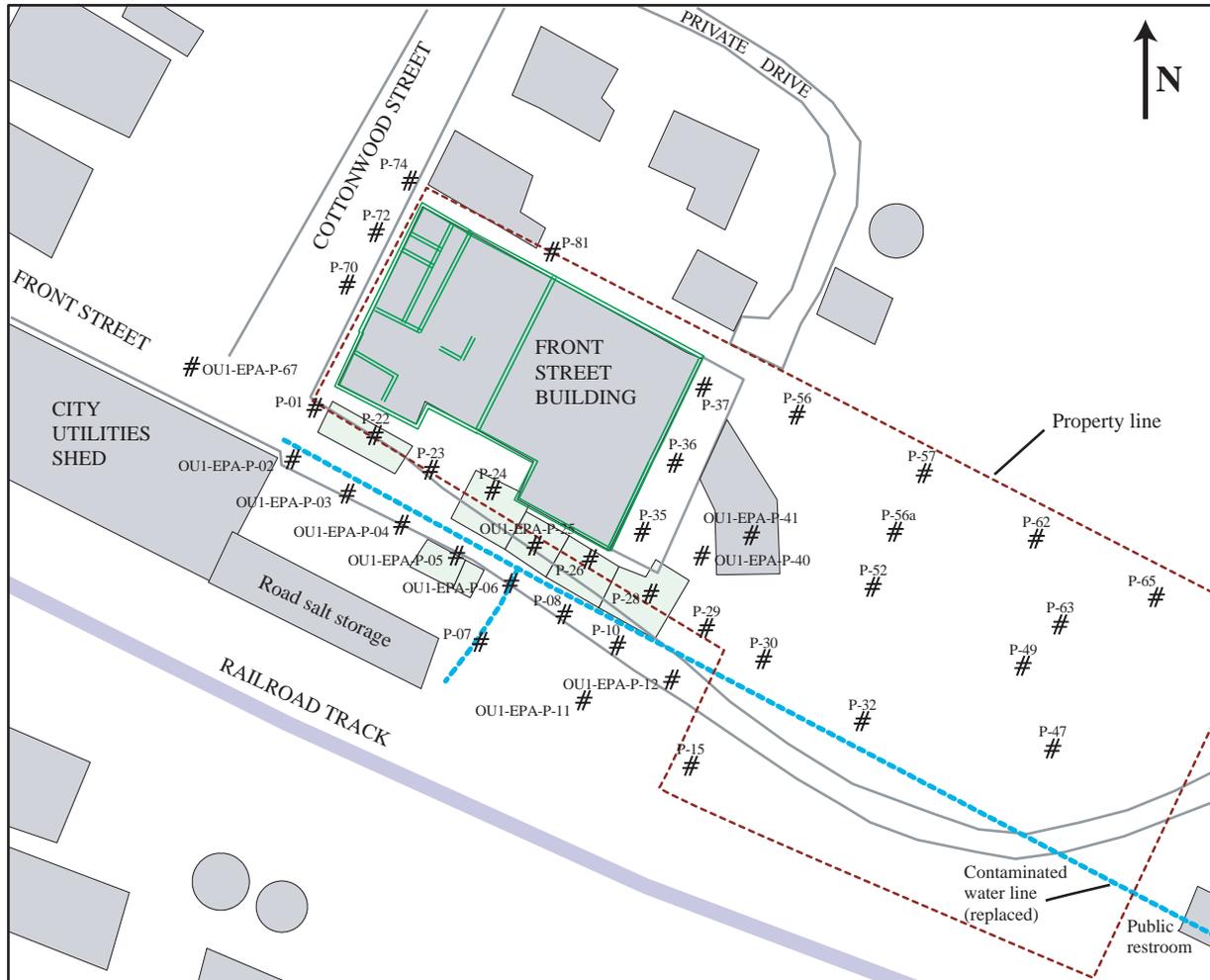


PCE CONCENTRATION IN TREE-CORE SAMPLES,
IN MICROGRAMS PER KILOGRAM WET WEIGHT

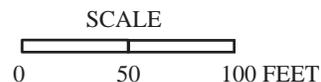
W2  PUBLIC-SUPPLY WELL AND NUMBER

-  NOT DETECTED
-  0.01-4.99
-  5.0-49.9
-  50-499
-  500-5,464

Figure 4-5. Location of sampling sites, estimated tetrachloroethene (PCE) concentrations in tree-core samples in the vicinity of OU1 (1999-2001), and conceptual extent of PCE contamination in the alluvial aquifer.



Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

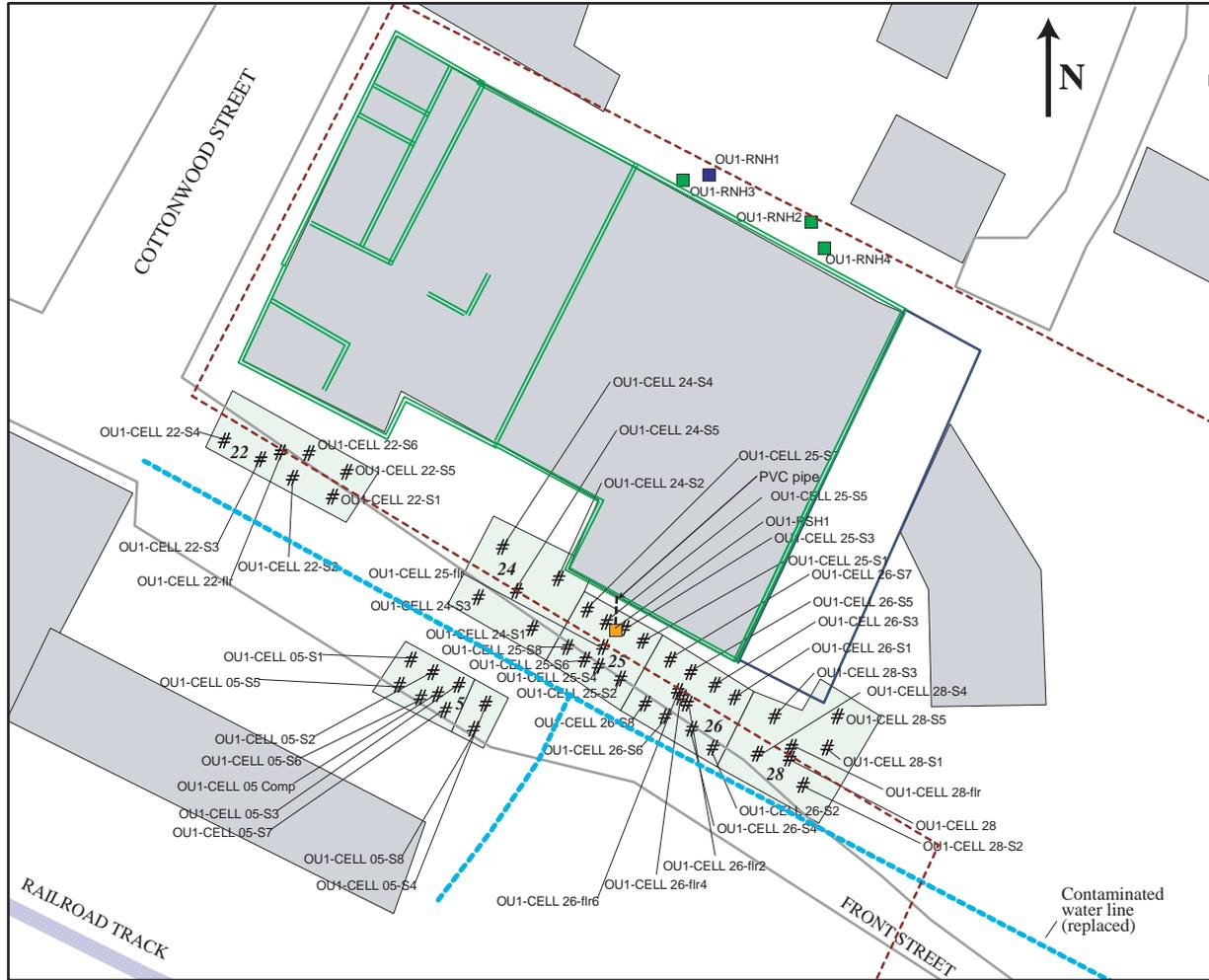


MAXIMUM PCE CONCENTRATION, IN MICROGRAMS PER KILOGRAM. LOCATIONS WITH "OU1-" PREFIX WERE ALSO SAMPLED BY THE U.S. GEOLOGICAL SURVEY

- # NOT DETECTED
- # 2-999
- # 1,000-19,199
- # 19,200-56,999
- # 57,000-569,999
- # 57,000-914,000

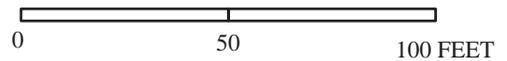
- ROAD OR CONCRETE PAD
- - - PROPERTY LINE (APPROXIMATE)
- BUILDING
- U.S. ENVIRONMENTAL PROTECTION AGENCY REMOVAL ACTION CELL

Figure 4-6. Location of sampling sites and maximum tetrachloroethene (PCE) concentrations in Phase I USEPA soil borings conducted at OU1 during June 2000. Concentrations of PCE determined by the U.S. Environmental Protection Agency Mobile Laboratory Program. Data on file at the U.S Environmental Protection Agency, Region VII.



Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

SCALE

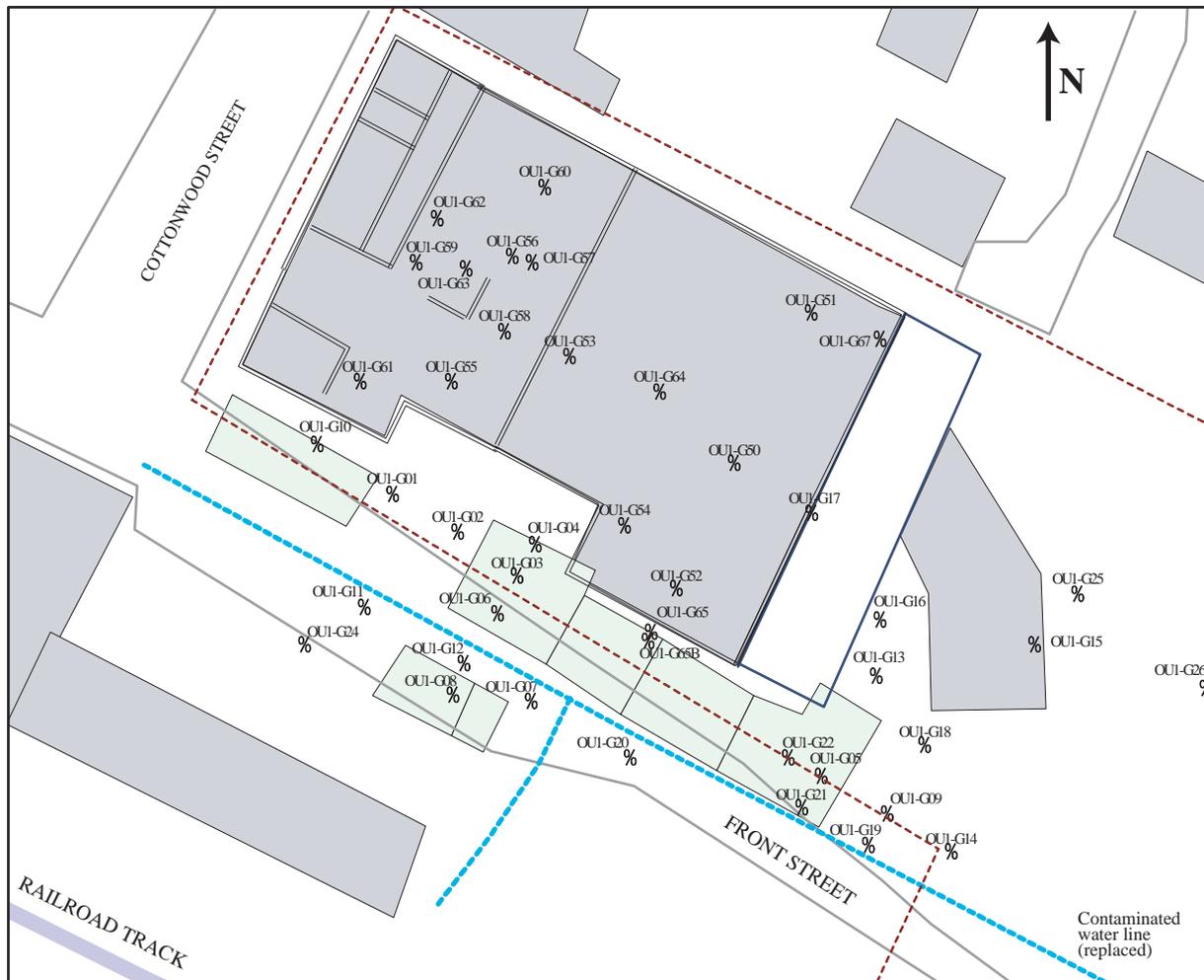


MAXIMUM PCE CONCENTRATION IN SOIL SAMPLE FROM CELL, IN MICROGRAMS PER KILOGRAM. SQUARE INDICATES HAND-AUGER BORING.

- # NOT DETECTED
- # 0.01-999
- # 1,000-19,199
- # 19,200-56,999
- # 57,000-569,999
- # 570,000-2,205,000

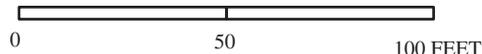
- ROAD OR CONCRETE PAD
- - - PROPERTY LINE (APPROXIMATE)
- BUILDING
- 26 U.S. ENVIRONMENTAL PROTECTION AGENCY REMOVAL ACTION CELL AND NUMBER

Figure 4-7. Location of sampling sites and maximum estimated tetrachloroethene (PCE) concentrations in Phase II soil samples collected during the removal of contaminated soils at OU1 (July-August 2000). Concentrations of PCE determined by portable gas chromatography (GC).



Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

SCALE

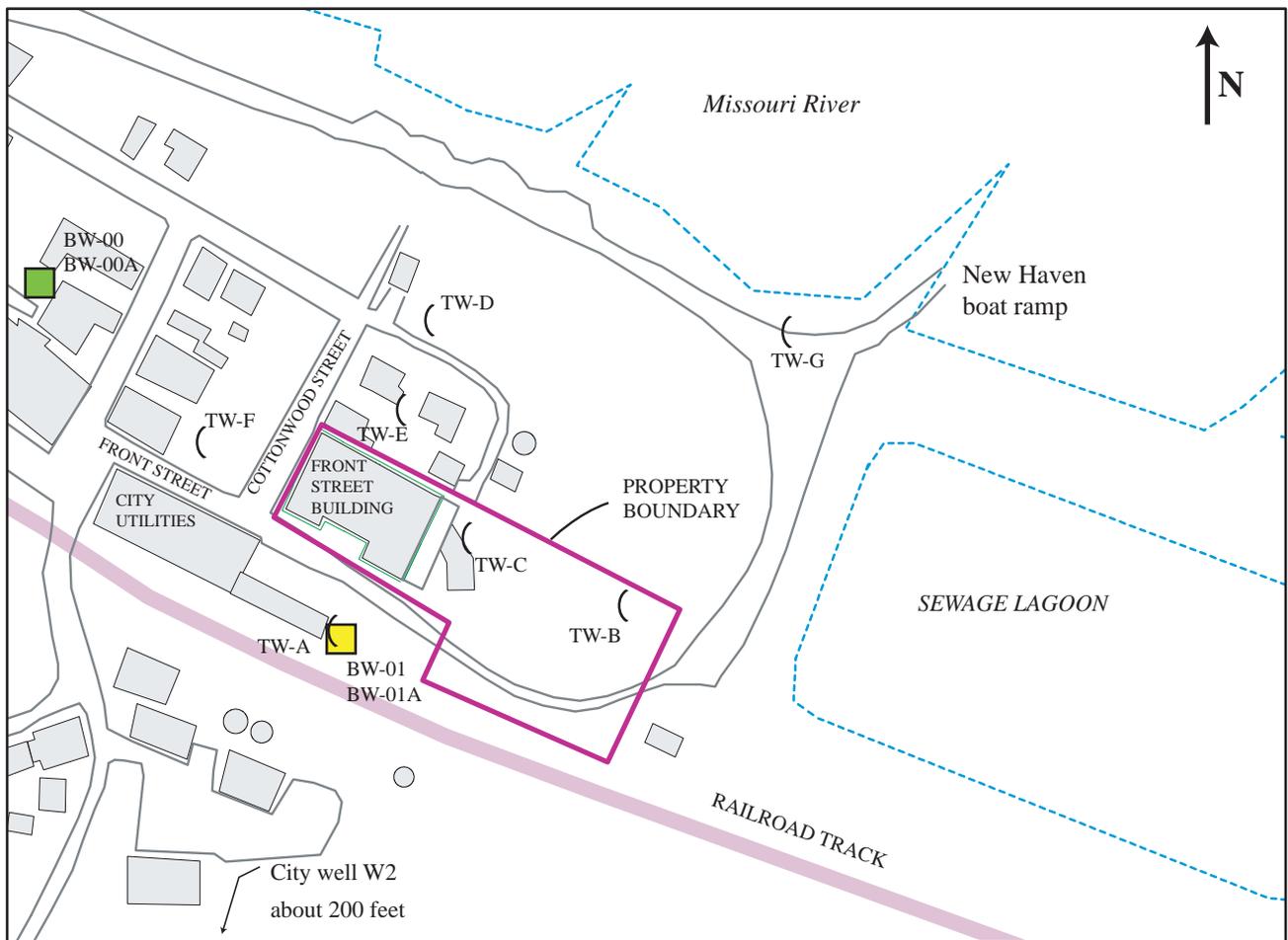


MAXIMUM PCE CONCENTRATION,
IN MICROGRAMS PER KILOGRAM

- % NOT DETECTED
- % 0.01-999
- % 1,000-19,199
- % 19,200-56,999
- % 57,000-569,999
- % 570,000-5,139,050

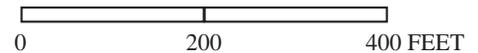
- ROAD OR CONCRETE PAD
- - - PROPERTY LINE (APPROXIMATE)
- BUILDING
- U.S. ENVIRONMENTAL PROTECTION AGENCY REMOVAL ACTION CELL

Figure 4-8. Location and number of sampling sites and maximum estimated tetrachloroethene (PCE) concentrations in Phase III soil borings at OU1 (January 2001 through March 2002). Concentrations of PCE determined by portable gas chromatograph (GC).



Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

SCALE

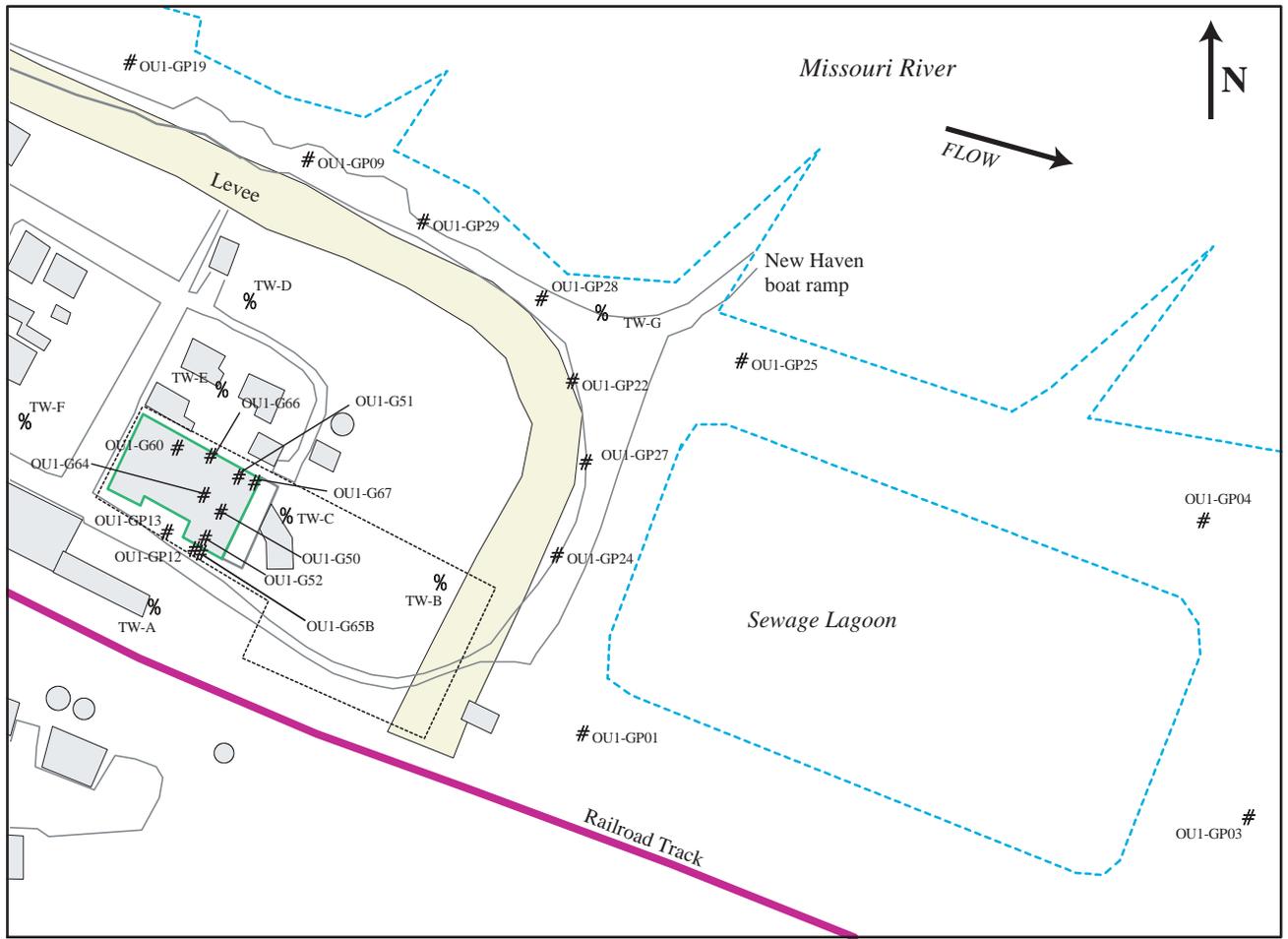


MAXIMUM PCE CONCENTRATION DETECTED, IN MICROGRAMS PER LITER. THE SQUARES INDICATE MONITORING WELLS IN BEDROCK AQUIFER

- (NOT DETECTED
- (0.01-4.99
- (5.0-49.99
- (50-499
- (500-670

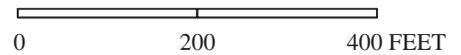
- STREET OR CONCRETE PAD
- - - - - STREAM OR WATER

Figure 4-9. Location of monitoring wells in the alluvial and bedrock aquifers in the vicinity of OU1 and maximum tetrachloroethene (PCE) concentrations in ground-water samples (Phase I and II ground-water investigations).



Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

SCALE



MAXIMUM PCE CONCENTRATION DETECTED, IN MICROGRAMS PER LITER. SQUARE INDICATES MONITORING WELL IN THE ALLUVIAL AQUIFER

- # NOT DETECTED
- # 0.1-4.99
- # 5.0-49.9
- # 50-499
- # 500-11,000

- STREAM
- ROAD OR CONCRETE PAD

Figure 4-10. Location of temporary well screens and monitoring wells in the alluvial aquifer and maximum tetrachloroethene (PCE) concentrations detected in ground-water samples at OU1. Combination of laboratory and portable gas-chromatograph (GC) data.

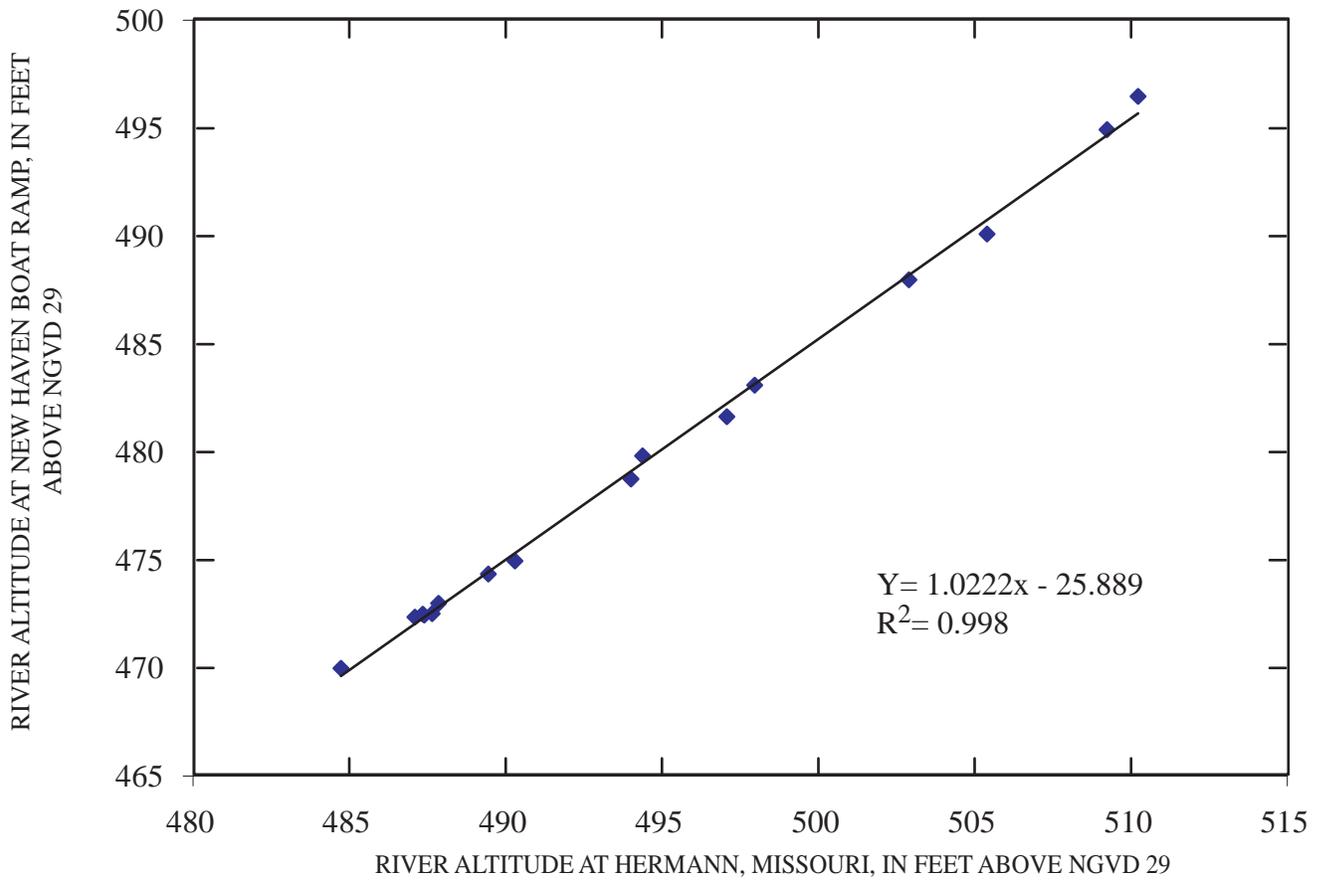
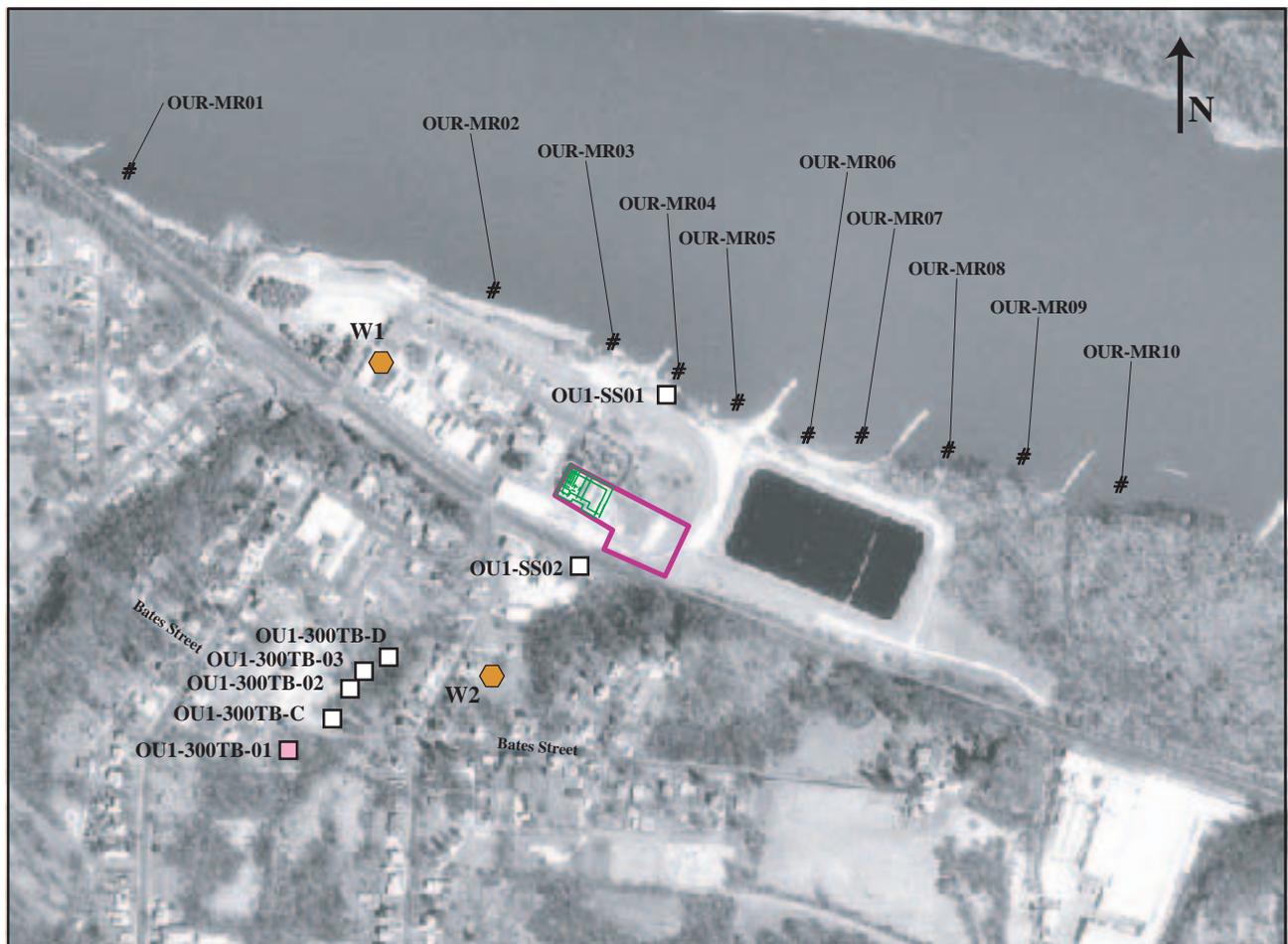
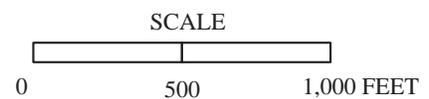


Figure 4-11. Relation between Missouri River stage at the U.S. Geological Survey continuous streamflow gaging station at Hermann, Missouri, and at the New Haven boat ramp.

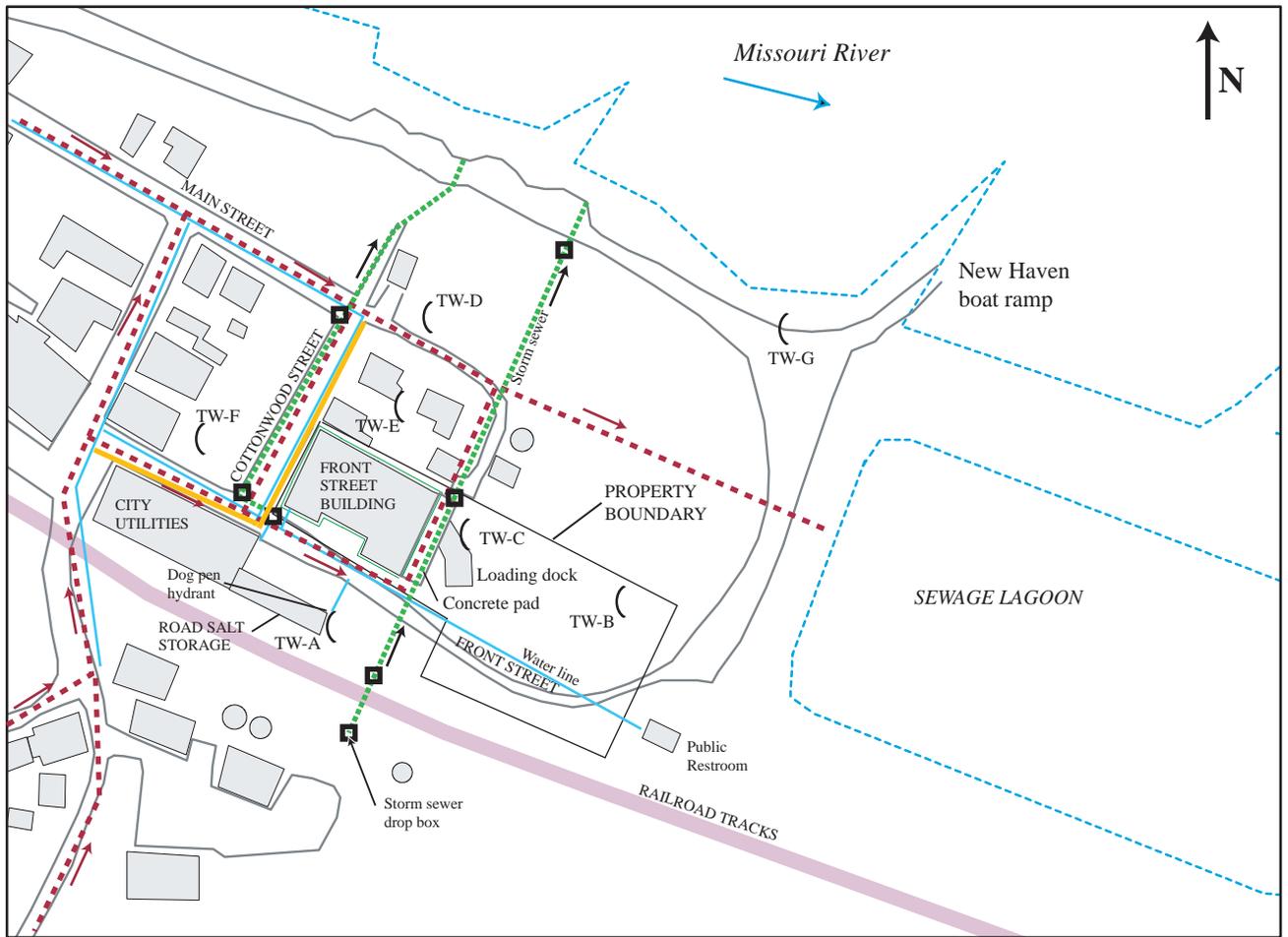


Base from U.S. Geological Survey digital orthophoto, 1:24,000, 1927
 Universal Transverse Mercator projection Zone 15



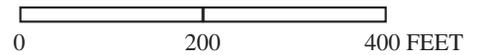
- OUR-MR02 # MISSOURI RIVER WATER AND BED-SEDIMENT SAMPLE SITE AND NUMBER
- OU1-SS01 □ STORM SEWER OR STREAM SAMPLE SAMPLE SITE AND NUMBER. PINK SHADE INDICATES TETRACHLOROETHENE (PCE) DETECTED
- W2 ○ CONTAMINATED PUBLIC-SUPPLY WELL AND NUMBER
- OU1 PROPERTY BOUNDARY (GREEN INDICATES BUILDING WALLS)

Figure 4-12. Location of Missouri River stream and bed-sediment sampling sites and stream and storm sewer sampling sites in the vicinity of OU1.



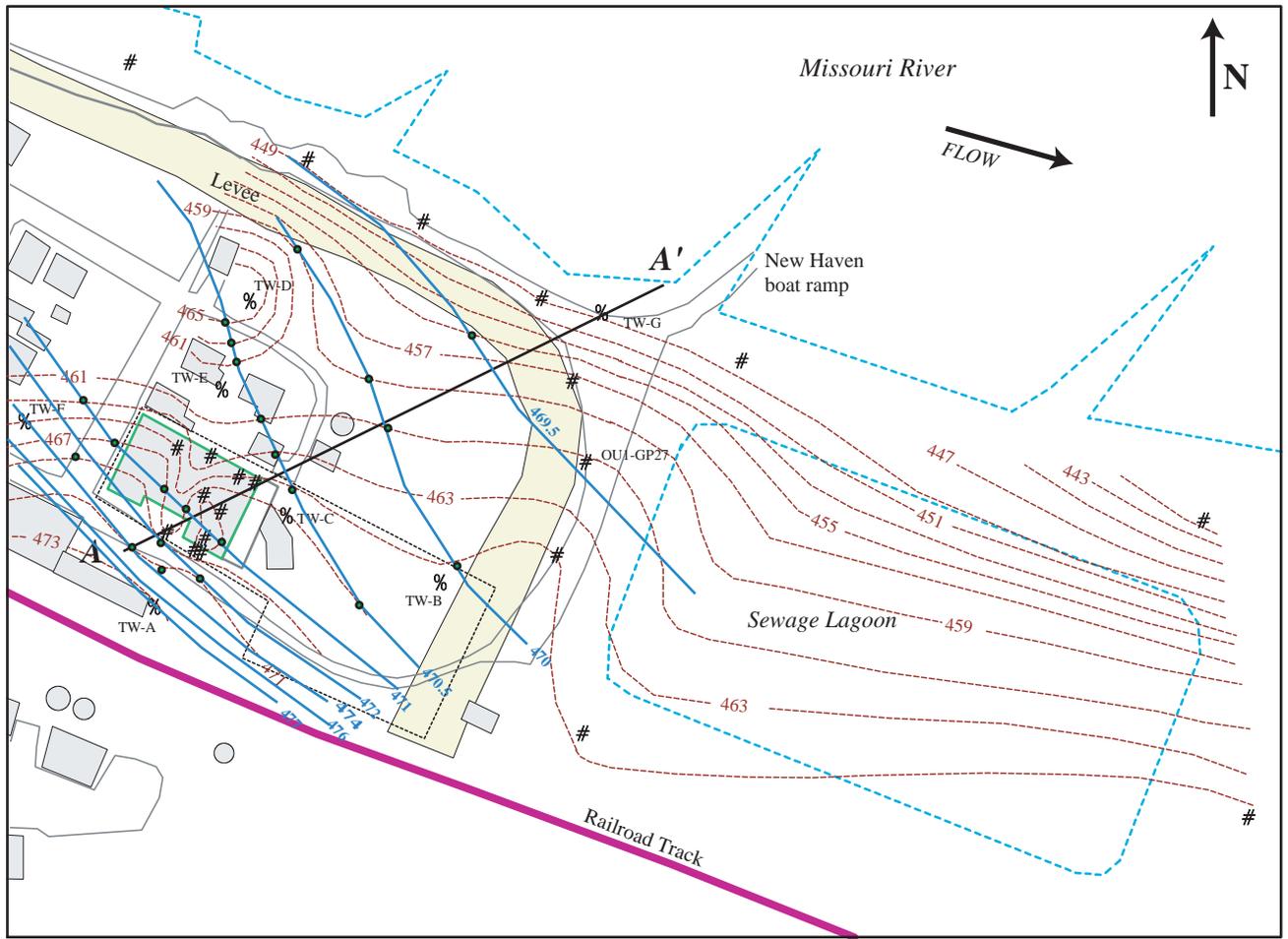
Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

SCALE



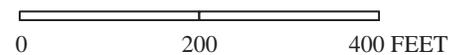
- | | |
|--|---|
| <p>TW-A (MONITORING WELL IN ALLUVIAL AQUIFER AND NUMBER</p> <p>--- SANITARY SEWER (APPROXIMATE LOCATION)</p> <p>--- STORM SEWER (APPROXIMATE LOCATION)</p> <p>--- WATER LINE (APPROXIMATE LOCATION)</p> <p>--- NATURAL GAS (APPROXIMATE LOCATION)</p> | <p>--- STREET OR CONCRETE PAD</p> <p>--- STREAM OR WATER</p> <p>--- DIRECTION OF FLOW</p> |
|--|---|

Figure 4-13. Primary features of the Front Street Site (OU1) and approximate locations of underground utilities.



Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

SCALE



MAXIMUM PCE CONCENTRATION, IN MICROGRAMS PER LITER. SQUARE INDICATES ALLUVIAL MONITORING WELL

- # NOT DETECTED
- # 0.1-4.99
- # 5.0-49.9
- # 50-499
- # 500-11,000

- STREAM
- ROAD OR CONCRETE PAD
- A—A' LINE OF HYDROGEOLOGIC SECTION (fig. 4-15)
- STRUCTURE CONTOUR ON TOP OF BEDROCK (BASE OF ALLUVIUM). CONTOUR INTERVAL 2 FEET. DATUM IS NGVD 29

Figure 4-14. Altitude of the top of bedrock (base of the alluvium) in the vicinity of OU1 and maximum tetrachloroethene (PCE) concentrations detected in alluvial monitoring wells and direct-push temporary well screen installations. Note PCE concentration at location OUI-G52 was estimated by portable gas-chromatograph (GC) analysis of water that accumulated inside the soil core tube.

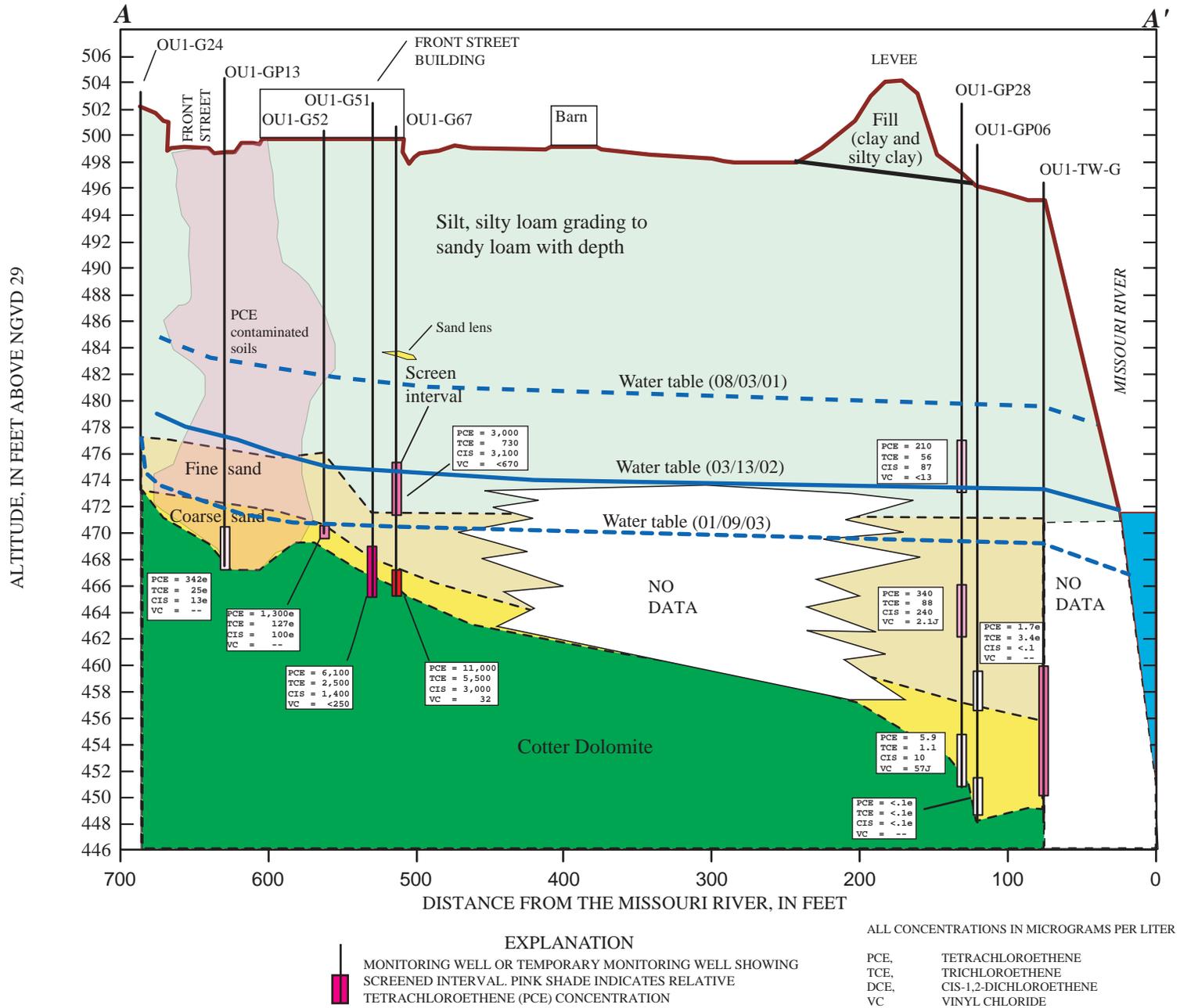


Figure 4-15. Generalized geohydrologic section through the Missouri River alluvium at OU1 (see figure 4-14 for location).

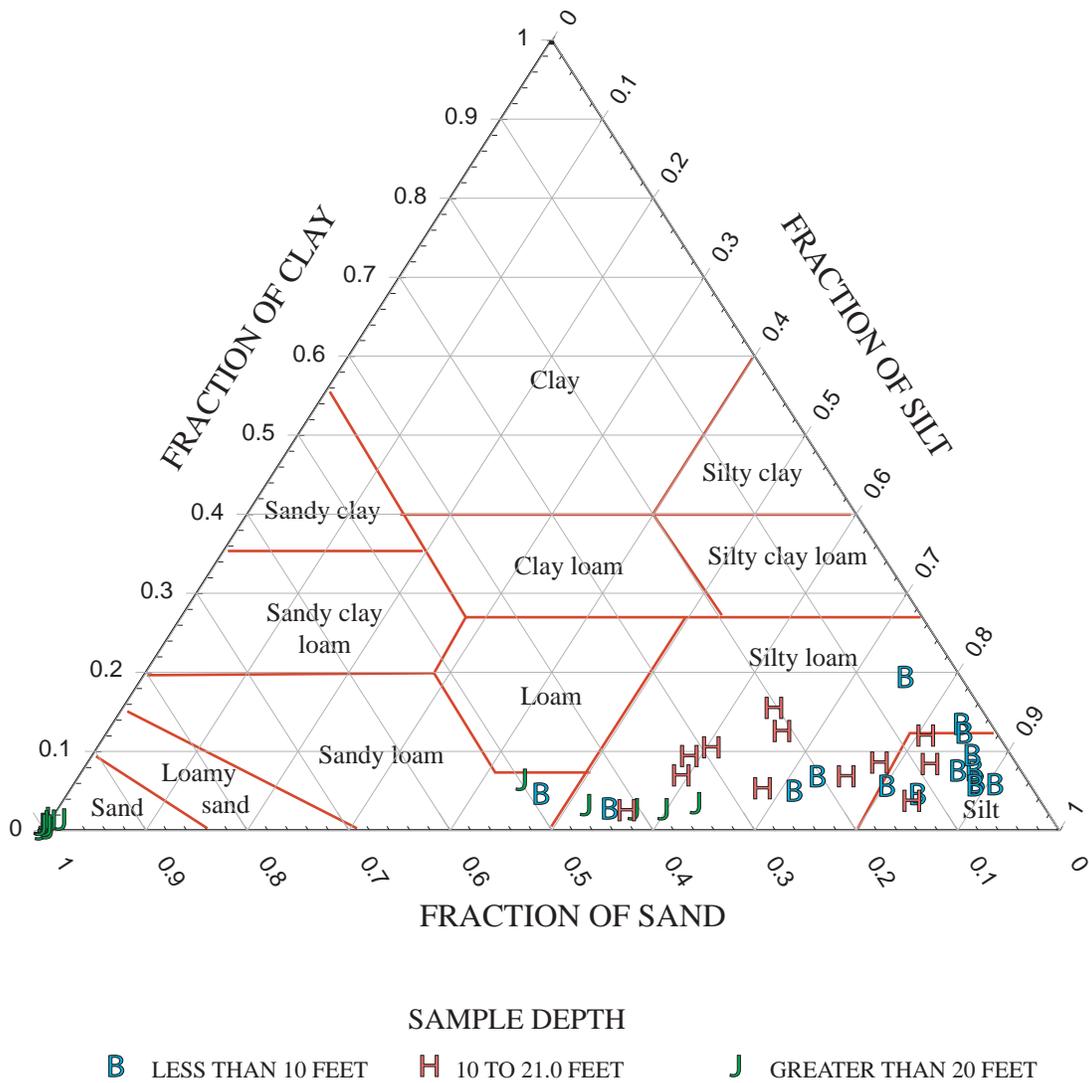


Figure 4-16. Grain-size and U.S. Department of Agriculture (USDA) classification of selected soil samples from boreholes G-51, G-60, and G65B at OU1.

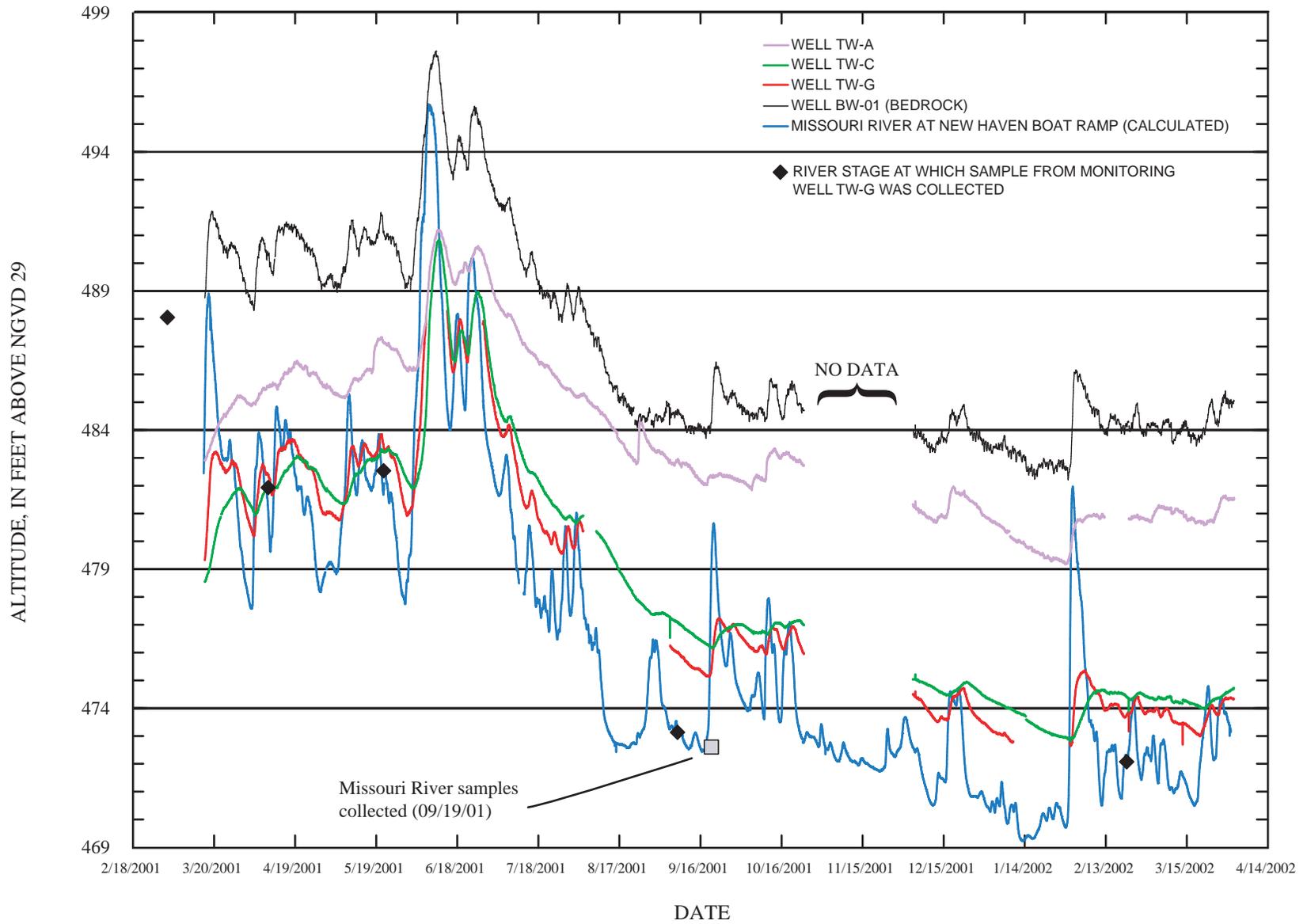
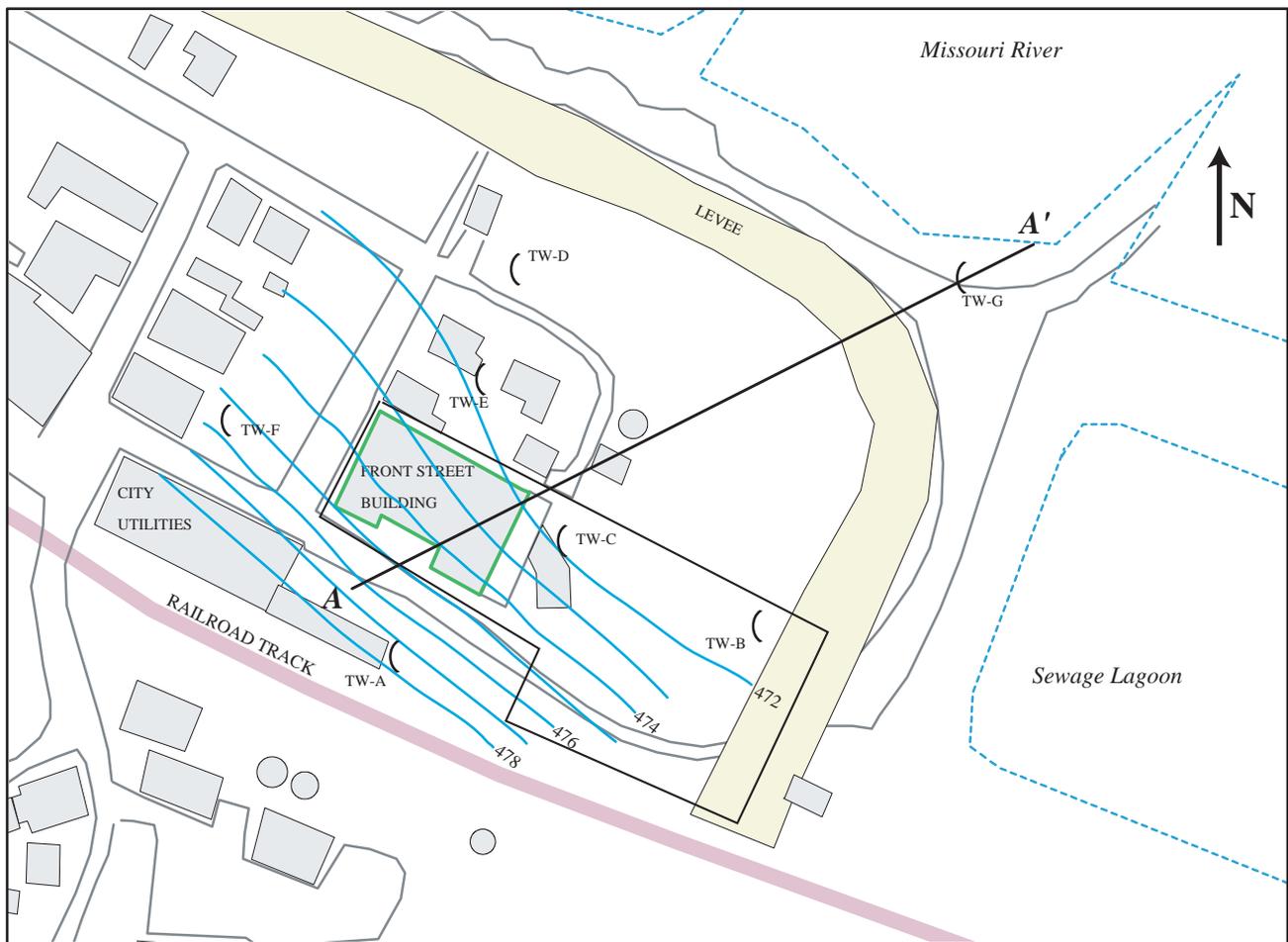


Figure 4-17. Water levels in monitoring wells in the alluvium (TW-A, TW-C, and TW-G) and bedrock (BW-01), and Missouri River stage from March 16, 2001, through April 01, 2002.



Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

SCALE

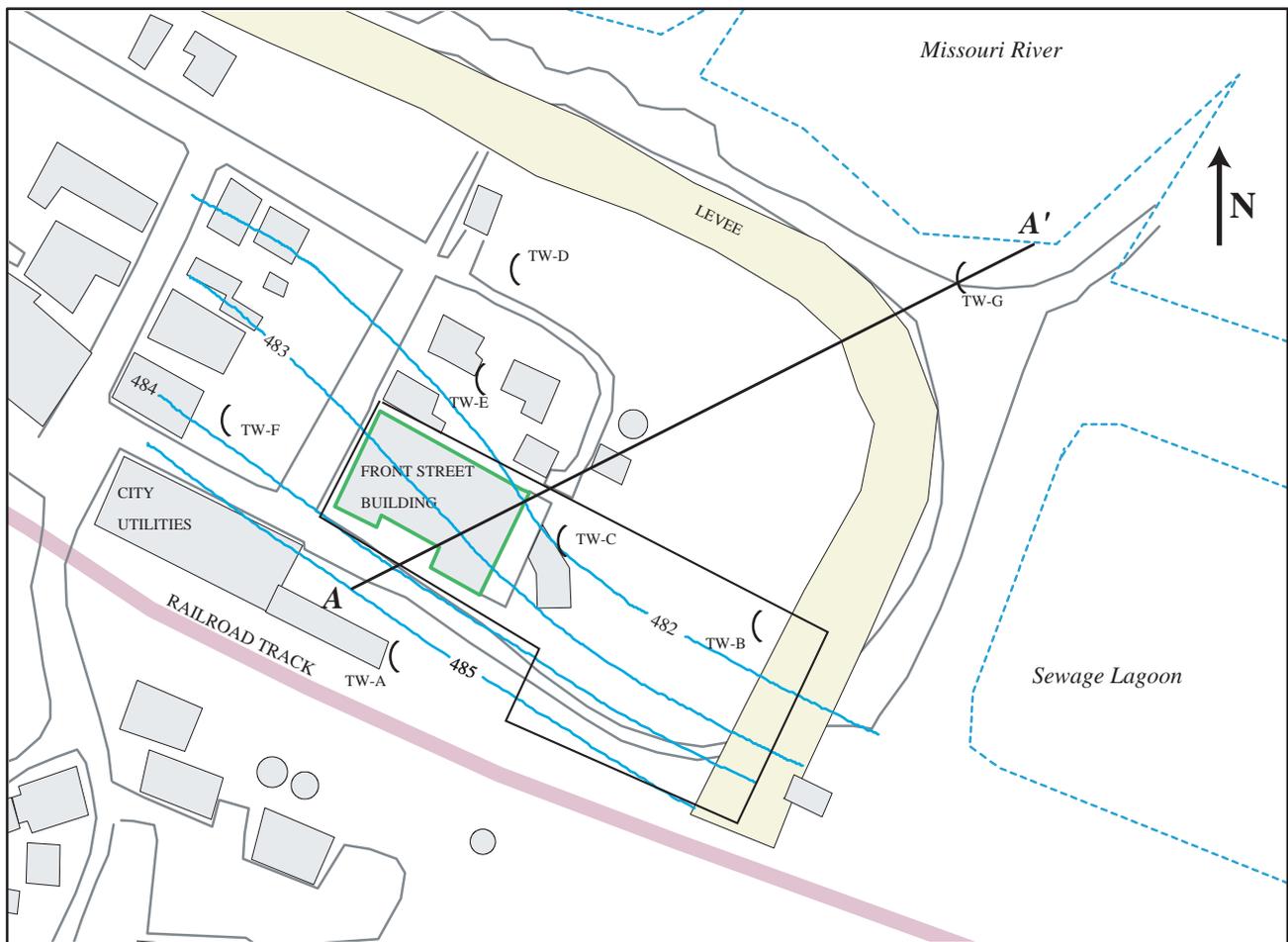


MAXIMUM PCE CONCENTRATION DETECTED IN MONITORING WELL, IN MICROGRAMS PER LITER

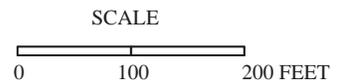
- (NOT DETECTED
- (0.01-4.99
- (5.0-49.99
- (50-499
- (500-670

- - - - - STREAM OR SURFACE-WATER FEATURE
- ROAD OR CONCRETE SLAB
- A — A' LINE OF HYDROGEOLOGIC SECTION (fig. 4-15)
- POTENTIOMETRIC CONTOUR IN THE ALLUVIAL AQUIFER. CONTOUR INTERVAL 1.0 FOOT

Figure 4-18. Potentiometric surface of the alluvial aquifer at OU1, January 23, 2001, and maximum tetrachloroethene (PCE) concentration detected in alluvial monitoring wells.



Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

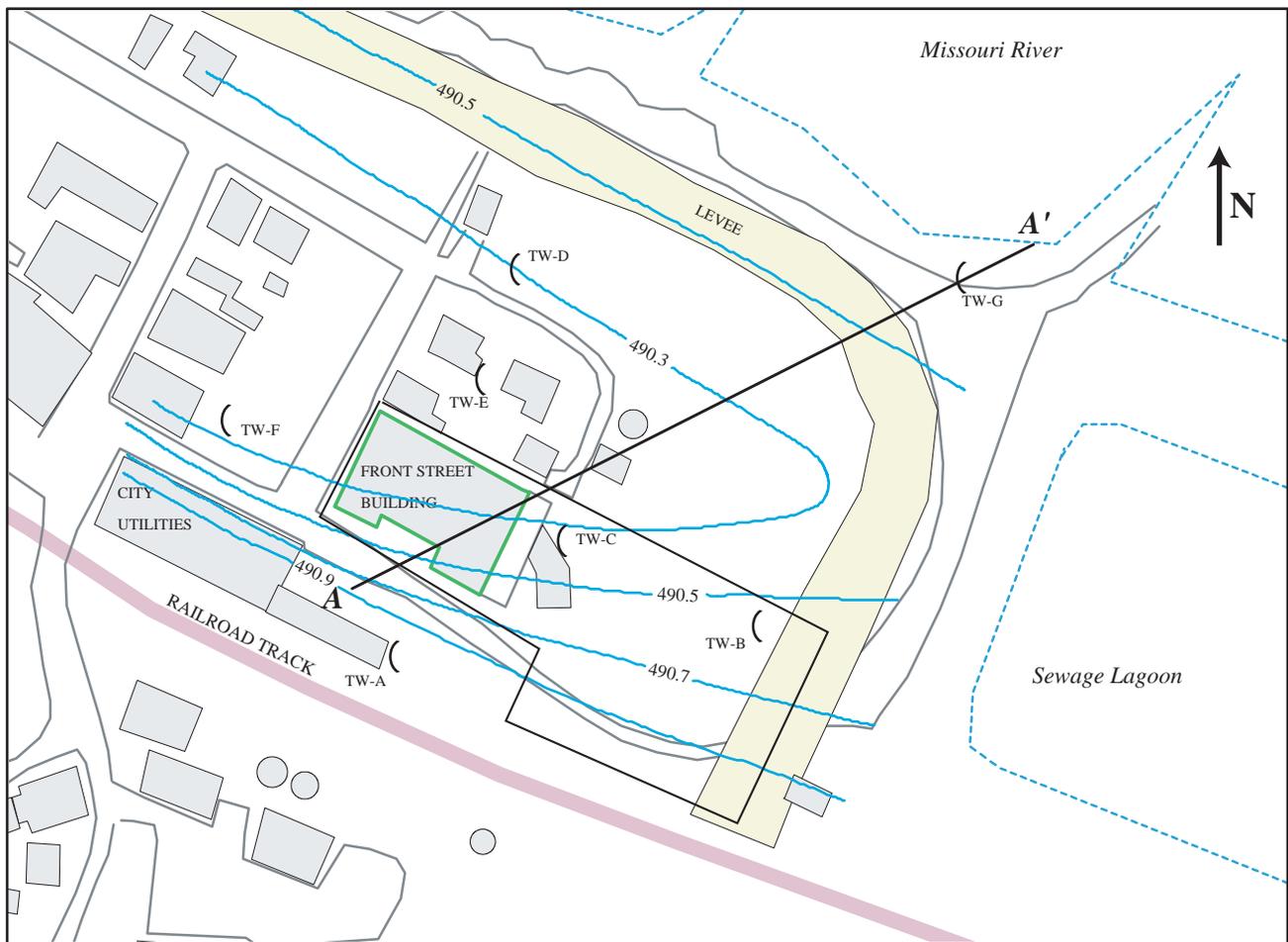


MAXIMUM PCE CONCENTRATION DETECTED IN MONITORING WELL, IN MICROGRAMS PER LITER

- (NOT DETECTED
- (0.01-4.99
- (5.0-49.99
- (50-499
- (500-670

- - - - - STREAM OR SURFACE-WATER FEATURE
- ROAD OR CONCRETE SLAB
- A — A' LINE OF HYDROGEOLOGIC SECTION (fig. 4-15)
- POTENTIOMETRIC CONTOUR IN THE ALLUVIAL AQUIFER. CONTOUR INTERVAL 1.0 FOOT

Figure 4-19. Potentiometric surface of the alluvial aquifer at OU1, April 11, 2001, and maximum tetrachloroethene (PCE) concentration detected in alluvial monitoring wells.



Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

MAXIMUM PCE CONCENTRATION DETECTED IN MONITORING WELL, IN MICROGRAMS PER LITER

- (NOT DETECTED
- (0.01-4.99
- (5.0-49.99
- (50-499
- (500-670

- - - - - STREAM OR SURFACE-WATER FEATURE
- ROAD OR CONCRETE SLAB
- A — A' LINE OF HYDROGEOLOGIC SECTION (fig. 4-15)
- POTENTIOMETRIC CONTOUR IN THE ALLUVIAL AQUIFER. CONTOUR INTERVAL 1.0 FOOT

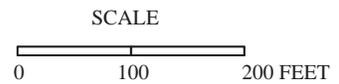
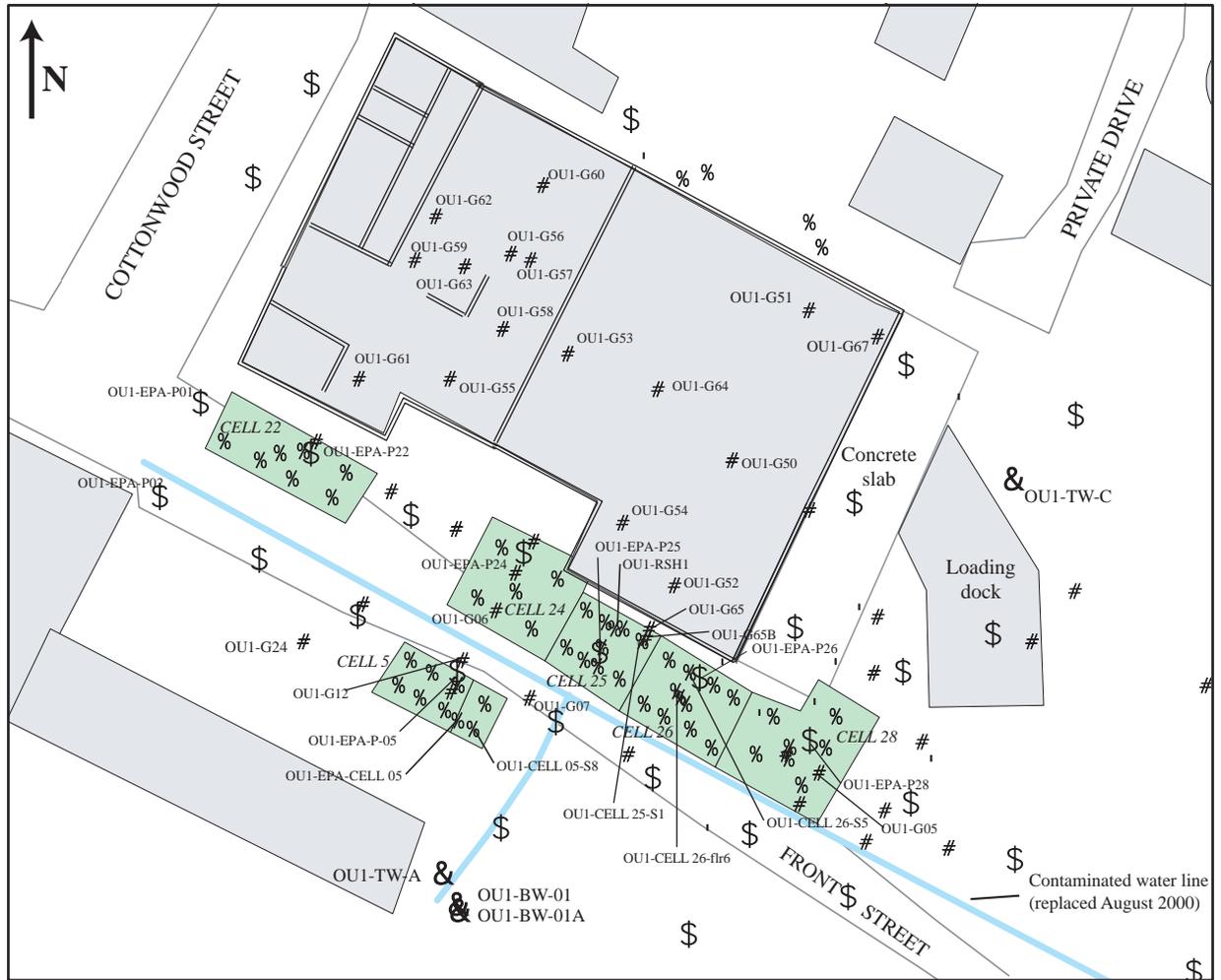


Figure 4-20. Potentiometric surface of the alluvial aquifer at OU1, June 12, 2001, and maximum tetrachloroethane (PCE) concentration detected in alluvial monitoring wells.



Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

SCALE



MAXIMUM PCE CONCENTRATION, IN MICROGRAMS PER KILOGRAM (TABLES OU1-4 and OU1-5)

- # LESS THAN 60
- # 60-5,699
- # 5,700^a-18,999
- # 19,000^b-56,999
- # 57,000-569,999
- # 570,000-6,200,000

SOIL SAMPLING CHRONOLOGY

- # Expanded Site Investigation (ESI), Jacobs Engineering Group (1994)
- \$ USEPA July 2000 (Removal action pre-excavation borings)
- % USEPA August 2000 removal action excavations
- # Remedial Investigation (RI) subsurface borings (USGS, 2001-2002)

- & MONITORING WELL
- % USEPA EXCAVATION (2000)
- BUILDING
- ROAD OR CONCRETE PAD

[^a Residential use Primary Remediation Goal (PRG) is 5,700 micrograms per kilogram]

[^b Industrial use Primary Remediation Goal (PRG) is 19,000 micrograms per kilogram]

Figure 4-21. Location and maximum tetrachloroethene (PCE) concentrations detected in soil samples during investigations at OU1. Concentrations are a combination of laboratory and portable gas chromatograph (GC) data.

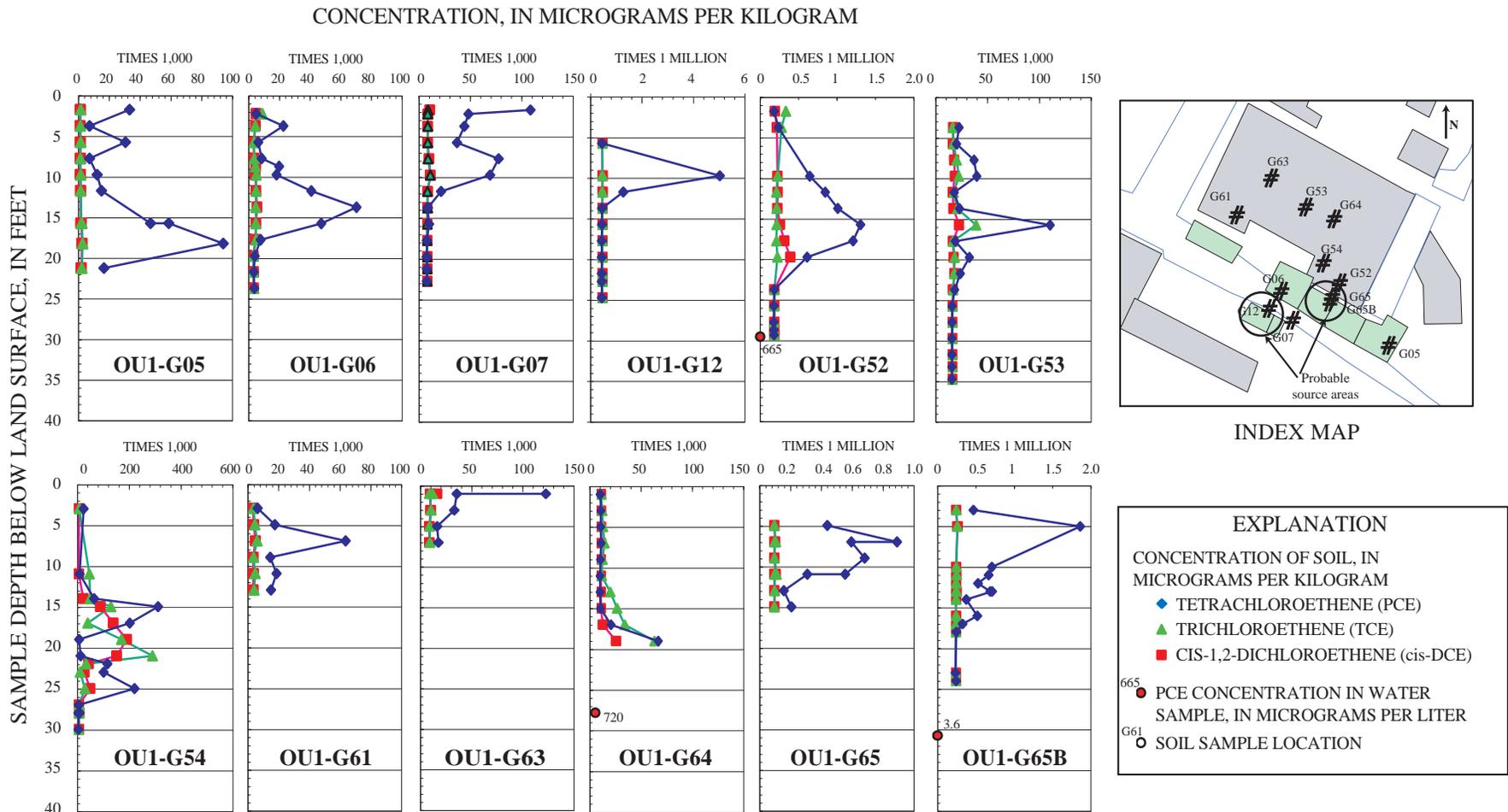
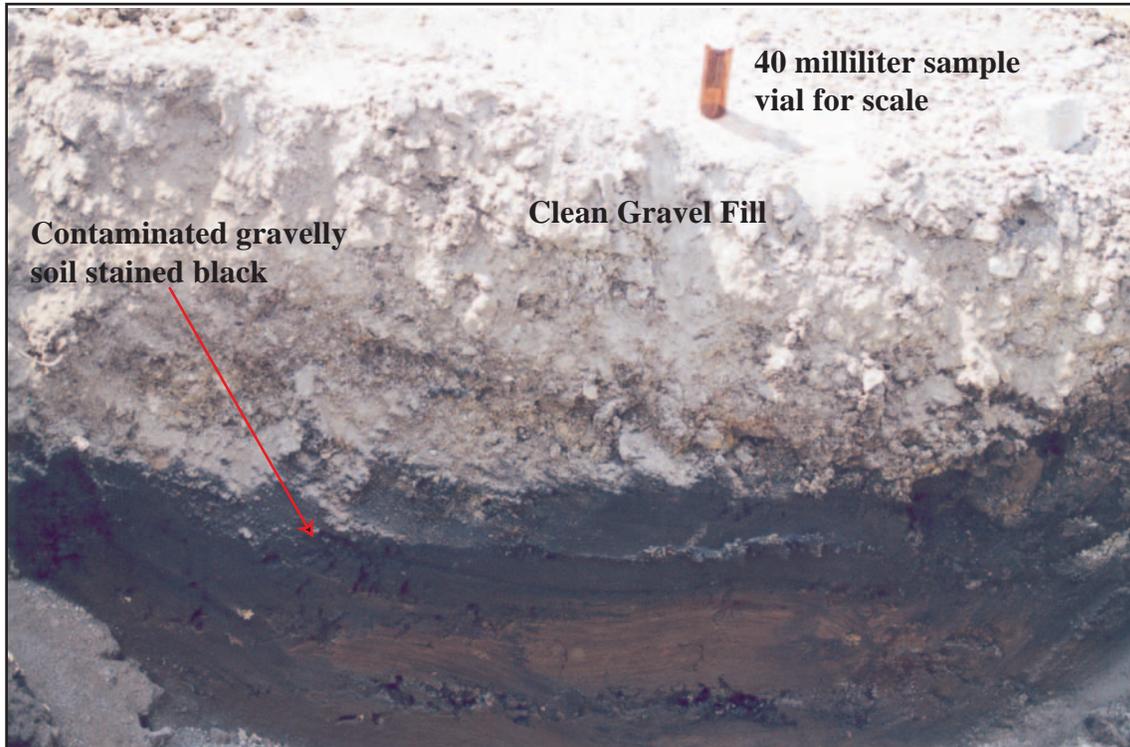
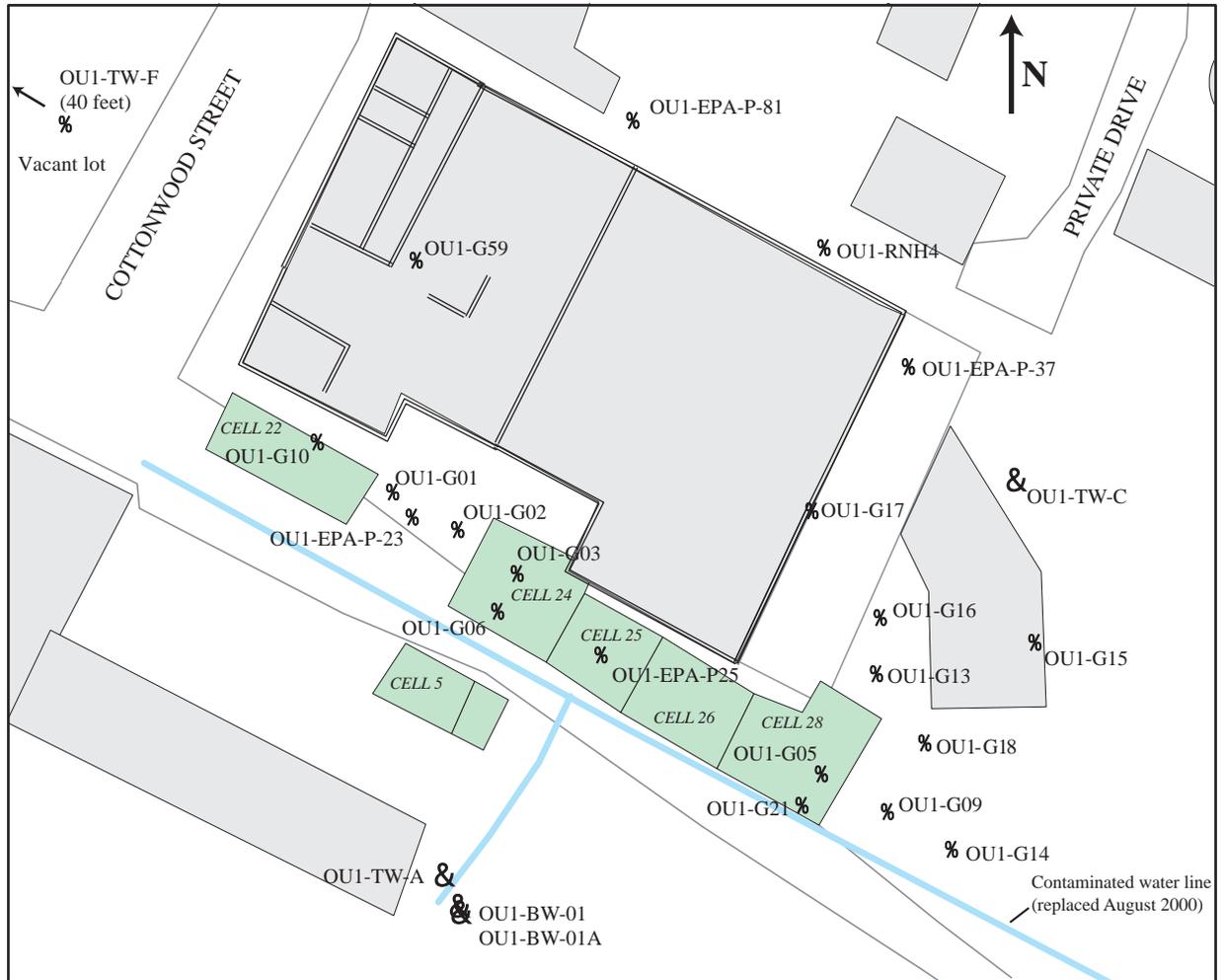


Figure 4-22. Vertical profiles of tetrachloroethene (PCE), trichloroethene (TCE), and cis-1,2-dichloroethene (cis-DCE) in soil samples from selected locations at OU1 containing more than 57,000 micrograms per kilogram PCE. Concentrations estimated using portable gas chromatography (GC).



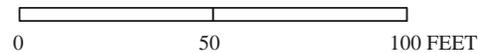
U.S. Geological Survey, August 14, 2000

Figure. 4-23. Photograph of tetrachloroethene (PCE) contaminated soil taken during the excavation of cell 5 during the U.S. Environmental Protection Agency (USEPA) removal action at OU1, looking at north face of excavation. Depth interval approximately 0 to 2 feet.



Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

SCALE



MAXIMUM Pb CONCENTRATION IN SOIL SAMPLES FROM EACH BORING LOCATION, IN MICROGRAMS PER KILOGRAM

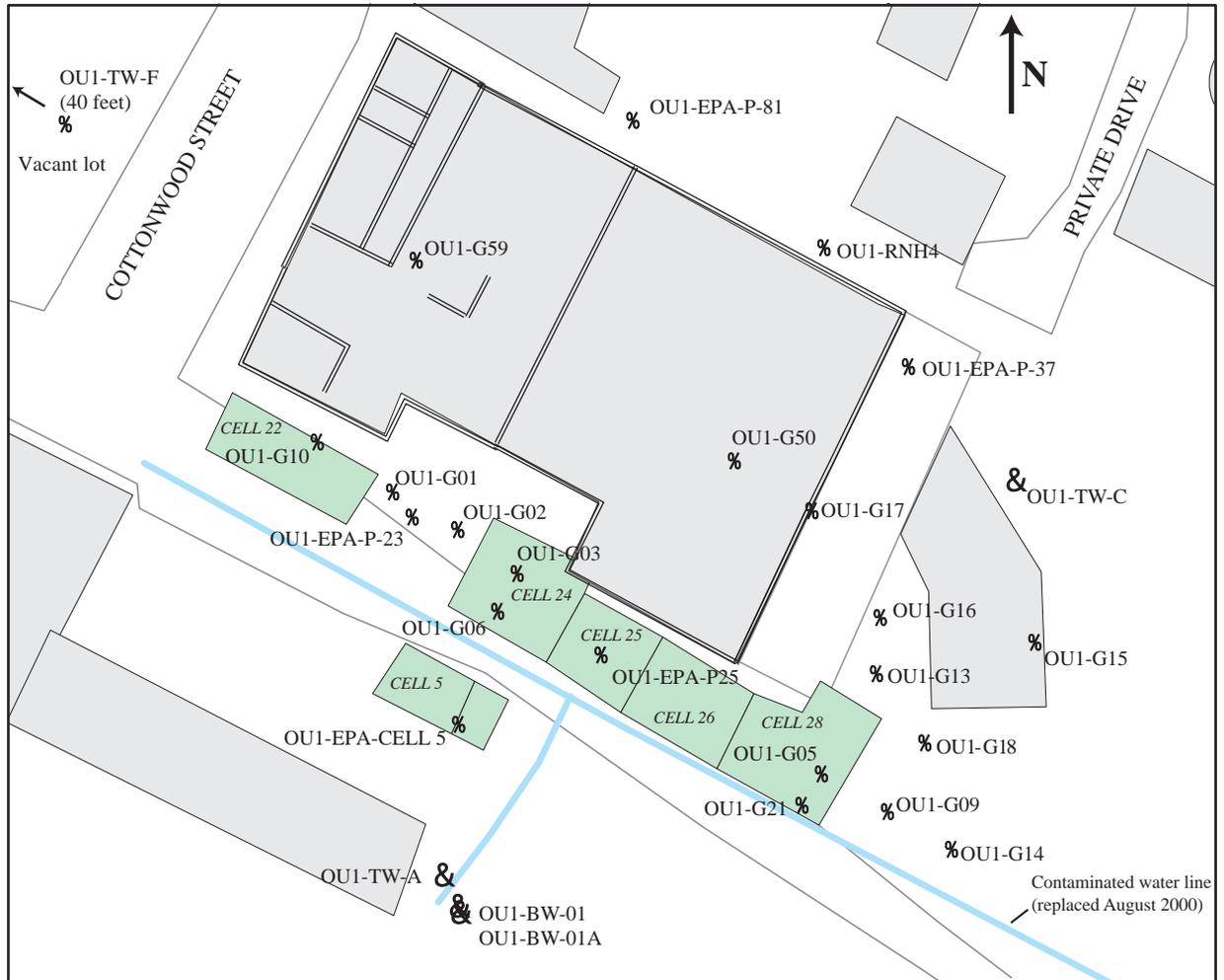
OU1-G06	%	8.3-28.7
	%	28.8 ^a -143
	%	144-399
	%	400 ^b -749
	%	750 ^c -11,600

OTHER SYMBOLS

- OU1-TW-A & MONITORING WELL AND NUMBER
- CELL 26 [Green Box] USEPA EXCAVATION (2000)
- [Grey Box] BUILDING
- ROAD OR CONCRETE PAD

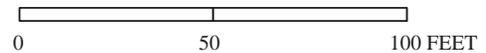
[^a Background concentration determined using data from Schalk and others (1998)]
 [^b Residential use Primary Remediation Goal (PRG) is 400 micrograms per kilogram]
 [^c Industrial use Primary Remediation Goal (PRG) is 750 micrograms per kilogram]

Figure 4-24. Summary of maximum lead (Pb) concentrations detected in soil samples from OU1.



Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

SCALE



MAXIMUM TOTAL SVOCs IN SOIL
SAMPLES FROM EACH BORING
LOCATION, IN MICROGRAMS PER
KILOGRAM

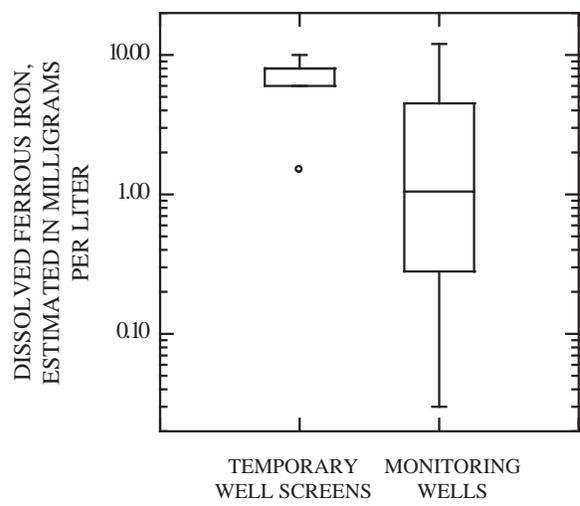
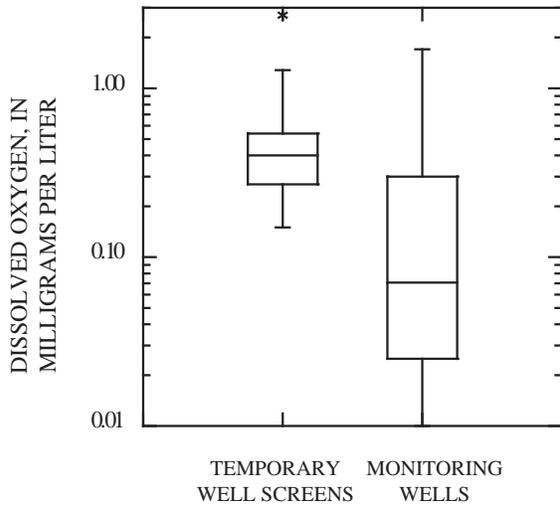
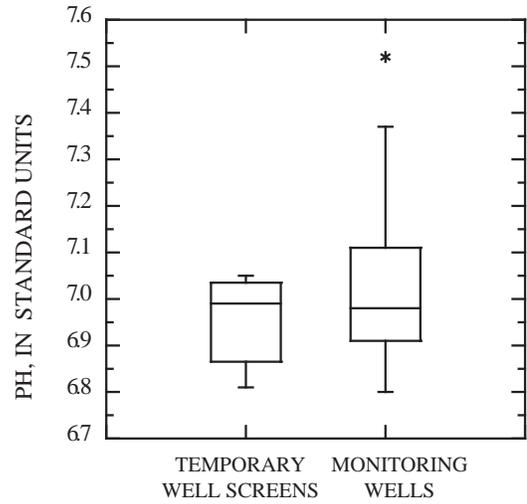
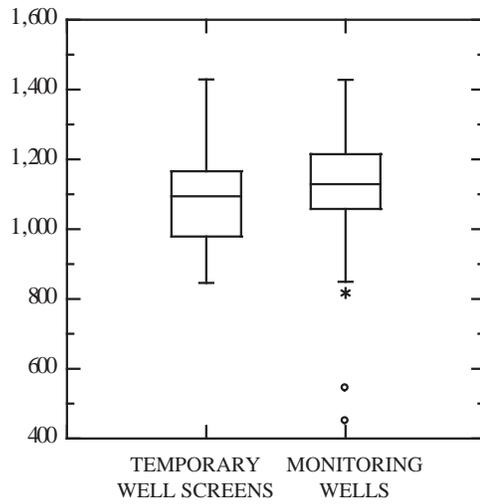
OU1-G06	%	NOT DETECTED
	%	1.0-99
	%	100-999
	%	1,000-9,999
	%	10,000-275,710

OTHER SYMBOLS

OU1-TW-A	&	MONITORING WELL AND NUMBER
	■	USEPA EXCAVATION (2000)
	■	BUILDING
	—	ROAD OR CONCRETE PAD

Figure 4-25. Maximum total concentration of semivolatile organic compounds (SVOCs) detected in soil samples from OU1.

SPECIFIC CONDUCTANCE, IN MICROSIEMENS PER CENTIMETER AT 25 DEGREES CELSIUS



EXPLANATION

- VALUE GREATER THAN 3.0 TIMES THE INTERQUARTILE RANGE ABOVE BOX
- * VALUE WITHIN 1.5 AND 3.0 TIMES THE INTERQUARTILE RANGE ABOVE BOX
- LARGEST VALUE WITHIN 1.5 TIMES THE INTERQUARTILE RANGE ABOVE BOX
- 75th PERCENTILE
- 50th PERCENTILE (MEDIAN)
- 25th PERCENTILE
- SMALLEST VALUE WITHIN 1.5 TIMES THE INTERQUARTILE RANGE BELOW BOX
- * VALUE WITHIN 1.5 AND 3.0 TIMES THE INTERQUARTILE RANGE BELOW BOX
- VALUE GREATER THAN 3.0 TIMES THE INTERQUARTILE RANGE BELOW BOX

Figure 4-26. Boxplots showing the range of specific conductance and pH values and concentrations of dissolved oxygen and ferrous iron (Fe²⁺) in monitoring wells and temporary well screen installations in the alluvial aquifer at OU1.

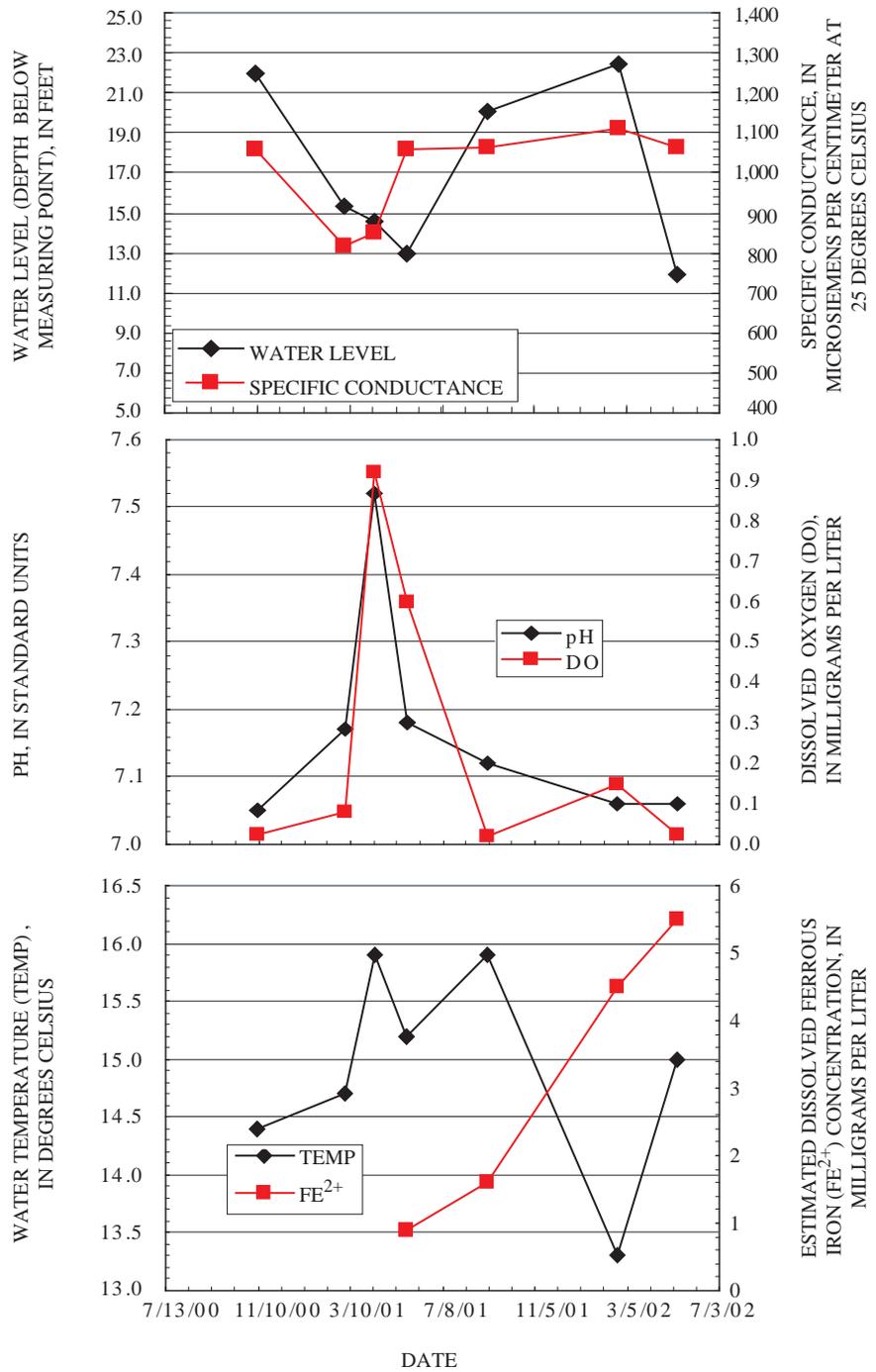
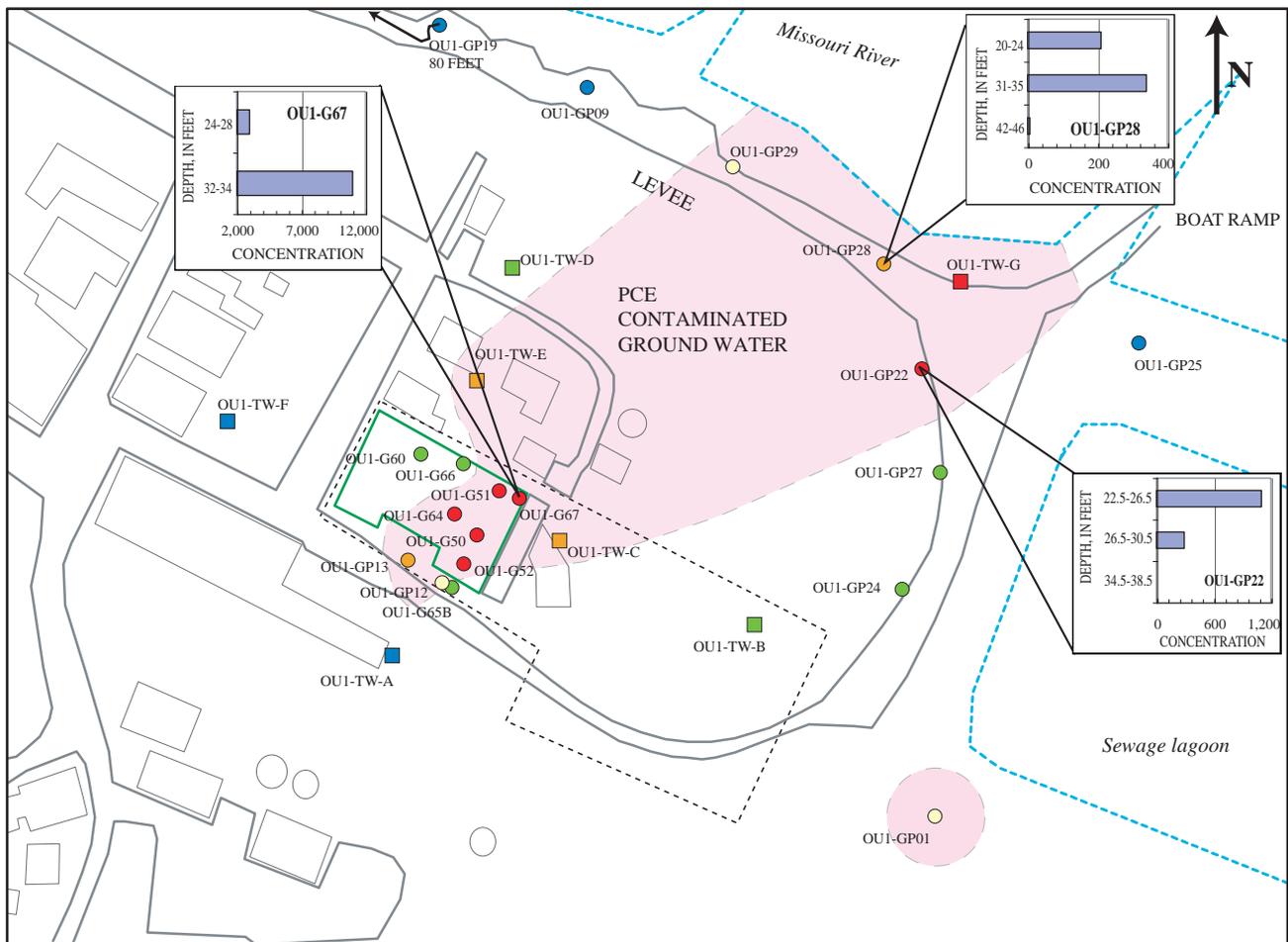
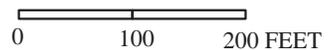


Figure 4-27. Variation in water level, specific conductance, pH, dissolved oxygen, temperature, and ferrous iron concentrations with time in samples from monitoring well TW-G.



Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

SCALE

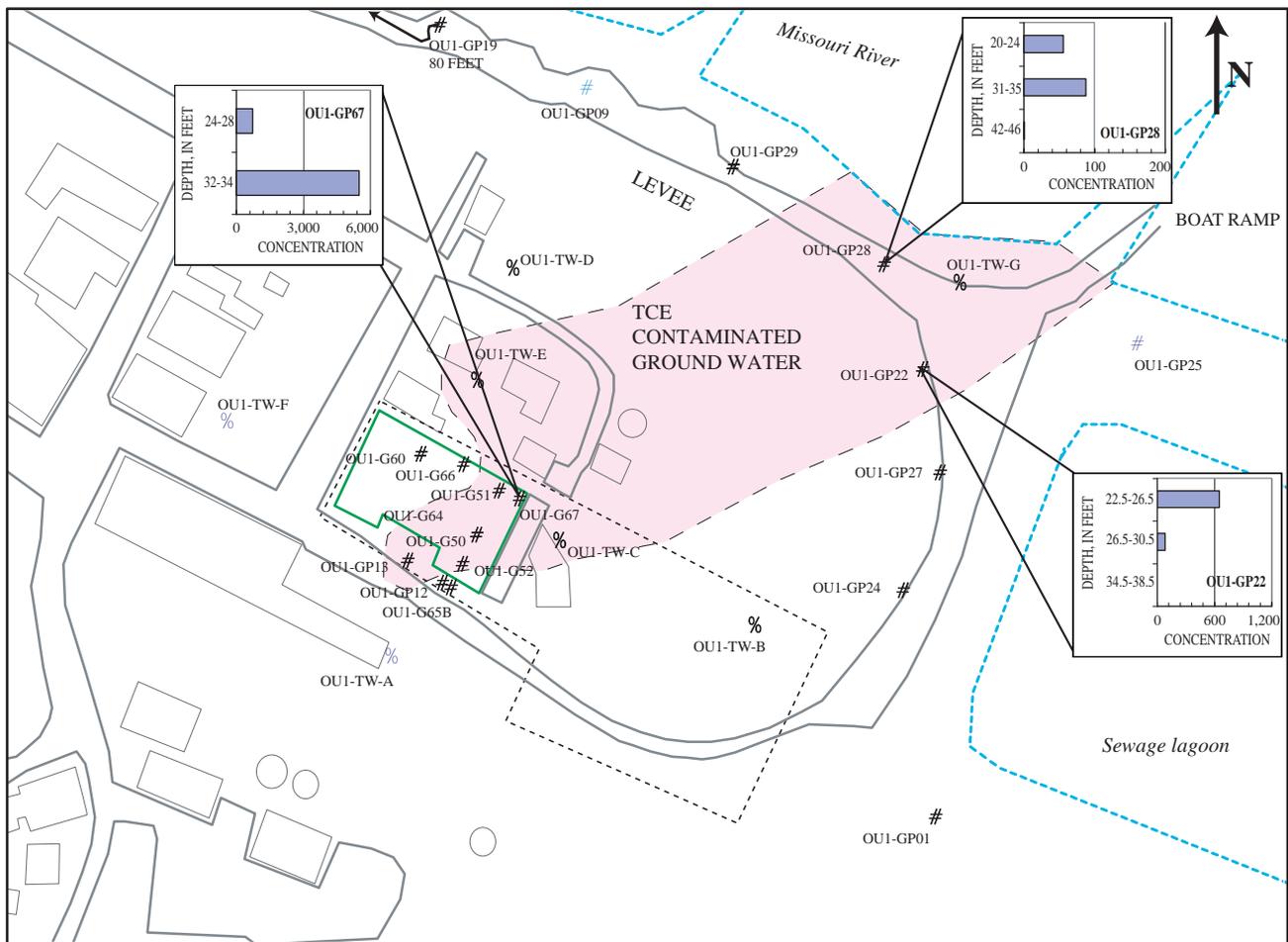


PCE, IN MICROGRAMS PER LITER.

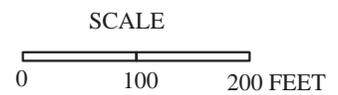
- # NOT DETECTED
- # 0.1-4.99
- # 5.0-49.9
- # 50-499
- # GREATER THAN 500

- STREAM
- ROAD OR CONCRETE PAD
- BUILDING
- - - - - PROPERTY LINE (APPROXIMATE)
- APPROXIMATE AREA CONTAINING PCE ABOVE THE MCL OF 5.0 MICROGRAMS PER LITER
- OU1-GP13 TEMPORARY WELL SCREEN AND NUMBER
- OU1-TW-A MONITORING WELL AND NUMBER

Figure 4-28. Summary of laboratory determined tetrachloroethene (PCE) concentrations in ground-water samples from the alluvial aquifer at operable unit OU1 [Note--data from temporary well screen locations G09, GP12, GP13, GP19, and G52 were determined using a portable gas chromatograph (GC)].



Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

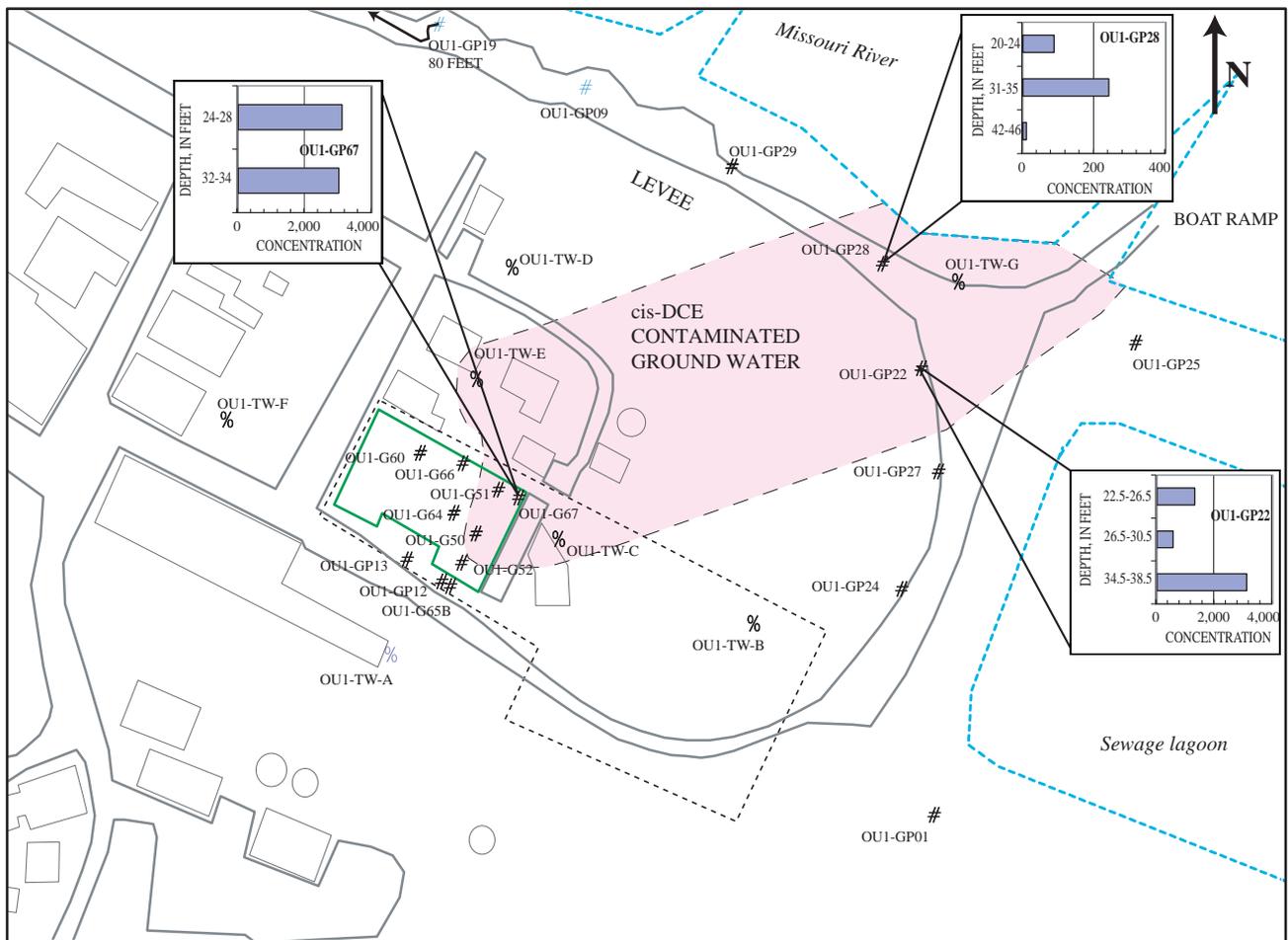


TCE, IN MICROGRAMS PER LITER

- # NOT DETECTED
- # 0.1-4.99
- # 5.0-49.9
- # 50-499
- # GREATER THAN 500

- STREAM
- ROAD OR CONCRETE PAD
- BUILDING
- PROPERTY LINE (APPROXIMATE)
- APPROXIMATE AREA CONTAINING TCE ABOVE THE MCL OF 5.0 MICROGRAMS PER LITER
- OU1-GP13 TEMPORARY WELL SCREEN AND NUMBER
- OU1-TW-A MONITORING WELL AND NUMBER

Figure 4-29. Summary of laboratory determined trichloroethene (TCE) concentrations in ground-water samples from the alluvial aquifer at operable unit OU1 [Note--data from temporary well screen locations G09, GP12, GP13, GP19, and G52 were determined using a portable gas chromatograph (GC)].



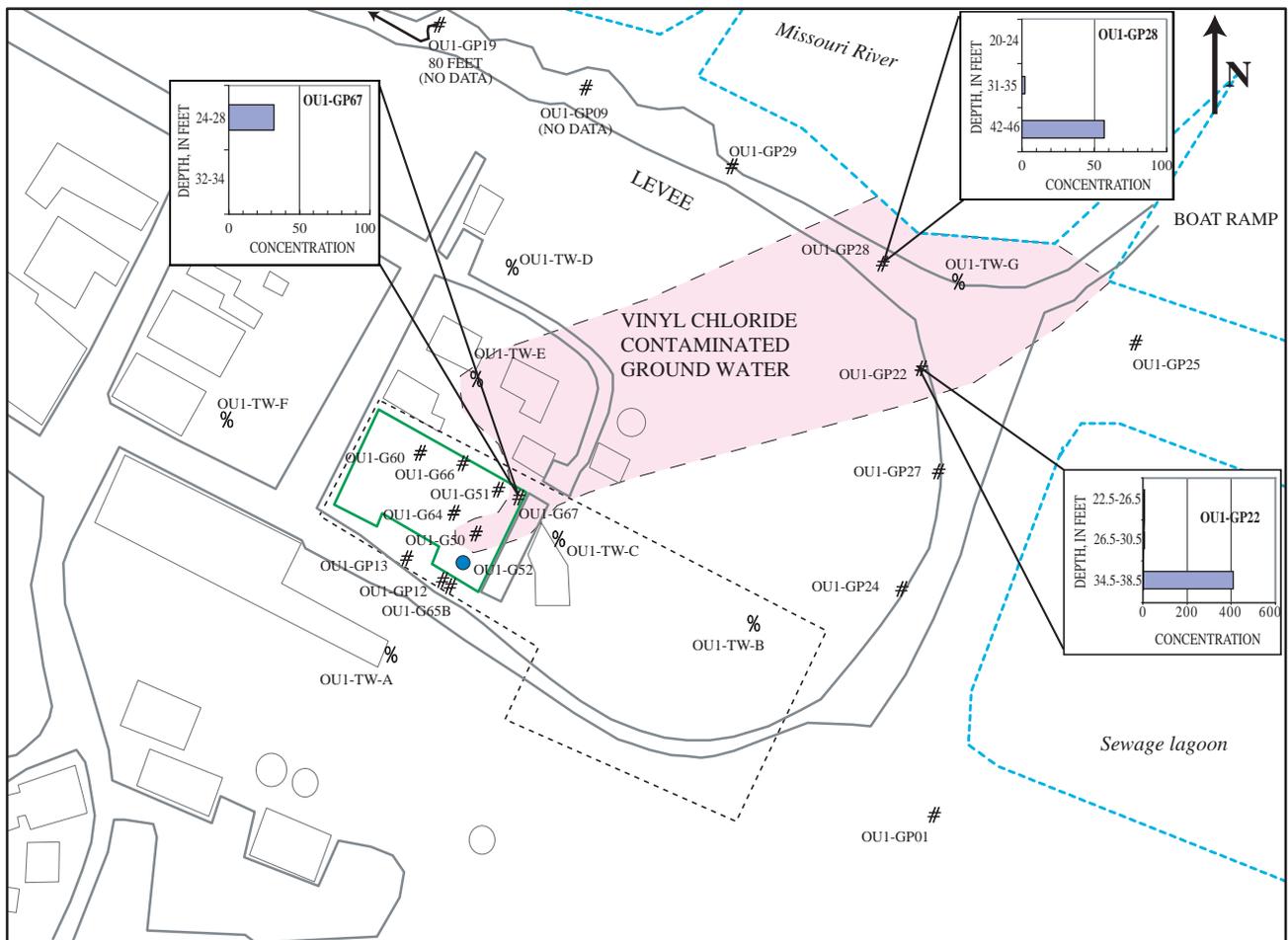
Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

cis-DCE, IN MICROGRAMS PER LITER.

- # NOT DETECTED
- # 0.1-4.99
- # 5.0-49.9
- # 50-499
- # GREATER THAN 500

- STREAM
- ROAD OR CONCRETE PAD
- BUILDING
- PROPERTY LINE (APPROXIMATE)
- APPROXIMATE AREA CONTAINING cis-DCE ABOVE THE MCL OF 70 MICROGRAMS PER LITER
- TEMPORARY WELL SCREEN AND NUMBER
- MONITORING WELL AND NUMBER

Figure 4-30. Summary of laboratory determined cis-1,2-dichloroethene (cis-DCE) concentrations in groundwater samples from the alluvial aquifer at operable unit OU1 [Note--data from temporary well screen locations G09, GP12, GP13, GP19, and G52 were determined using a portable gas chromatograph (GC)].



Base from U.S. Geological Survey digital data, 1:100,000, 1927 Universal Transverse Mercator projection Zone 15

VC, IN MICROGRAMS PER LITER.

- # NO DATA
- # NOT DETECTED
- # 0.1-4.99
- # 5.0-49.9
- # 50-499
- # GREATER THAN 500

- STREAM
- ROAD OR CONCRETE PAD
- BUILDING
- - - - - PROPERTY LINE (APPROXIMATE)
- APPROXIMATE AREA CONTAINING VC ABOVE THE MCL OF 2.0 MICROGRAMS PER LITER
- OU1-GP13 TEMPORARY WELL SCREEN AND NUMBER
- OU1-TW-A MONITORING WELL AND NUMBER

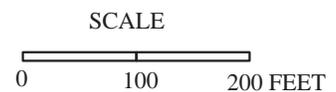


Figure 4-31. Summary of laboratory determined vinyl chloride (VC) concentrations in ground-water samples from the alluvial aquifer at operable unit OU1 [Note-- data from locations GP09, GP12, GP13, GP19, and G52 were determined using a portable gas chromatograph (GC)].

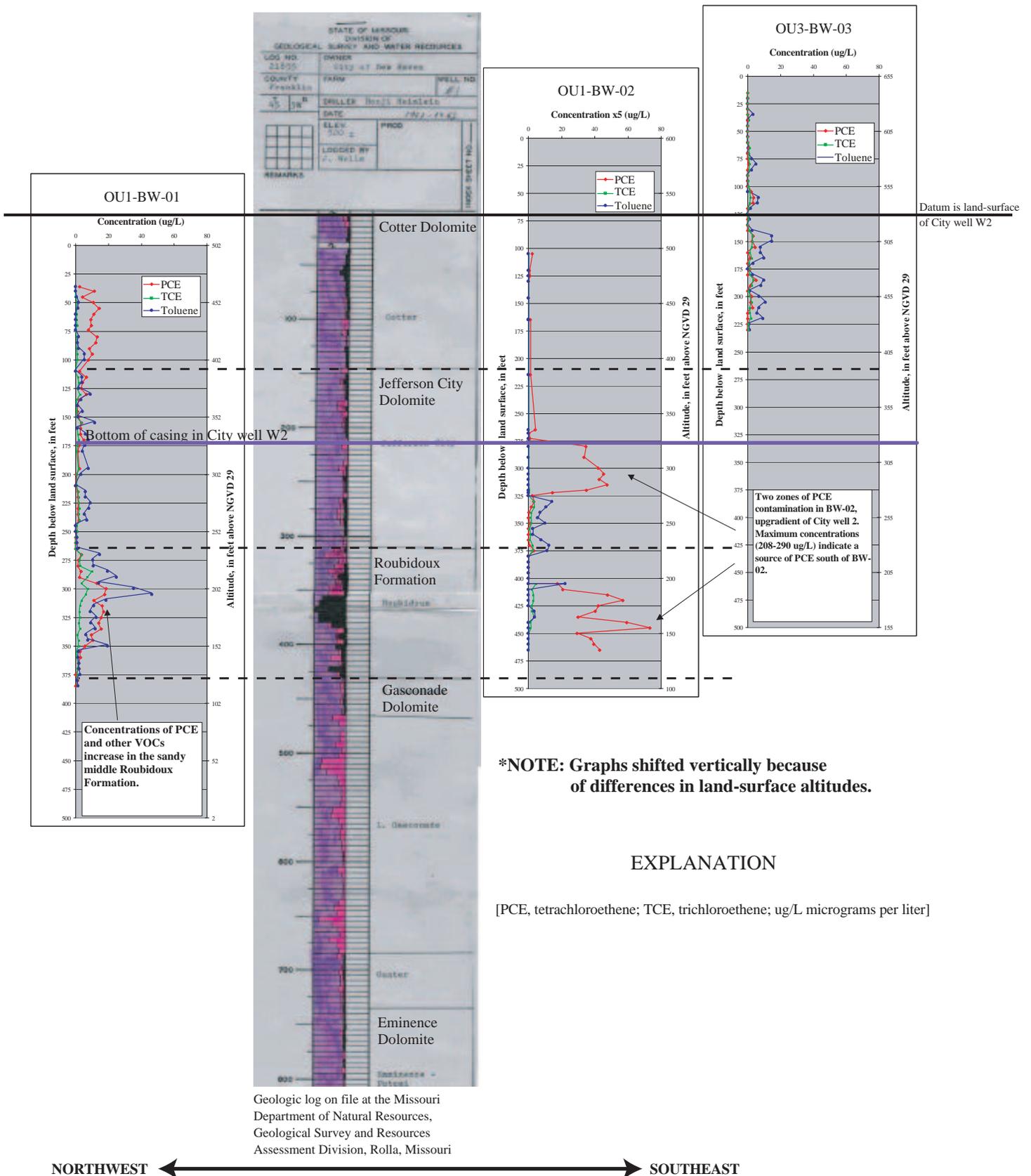
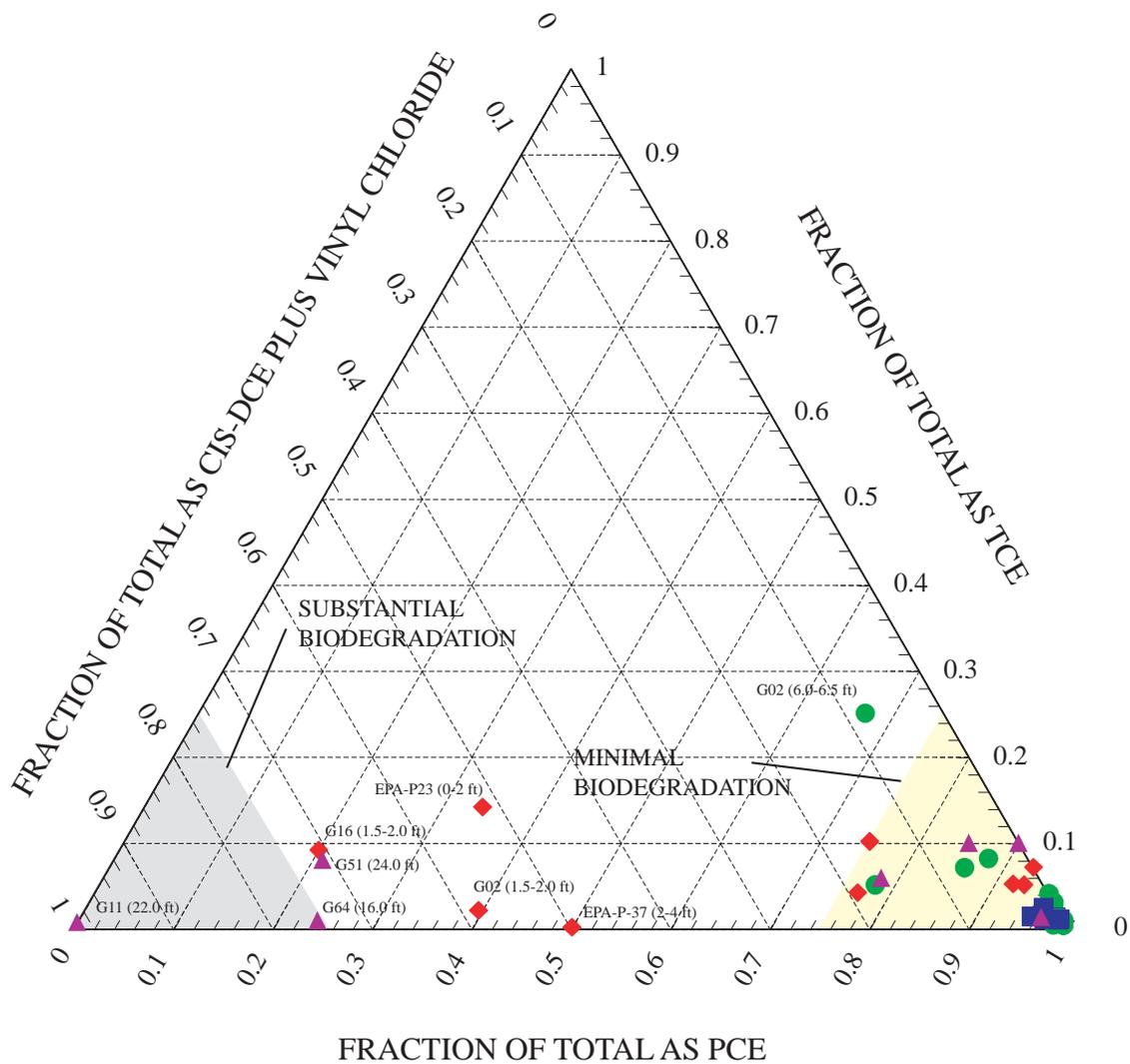


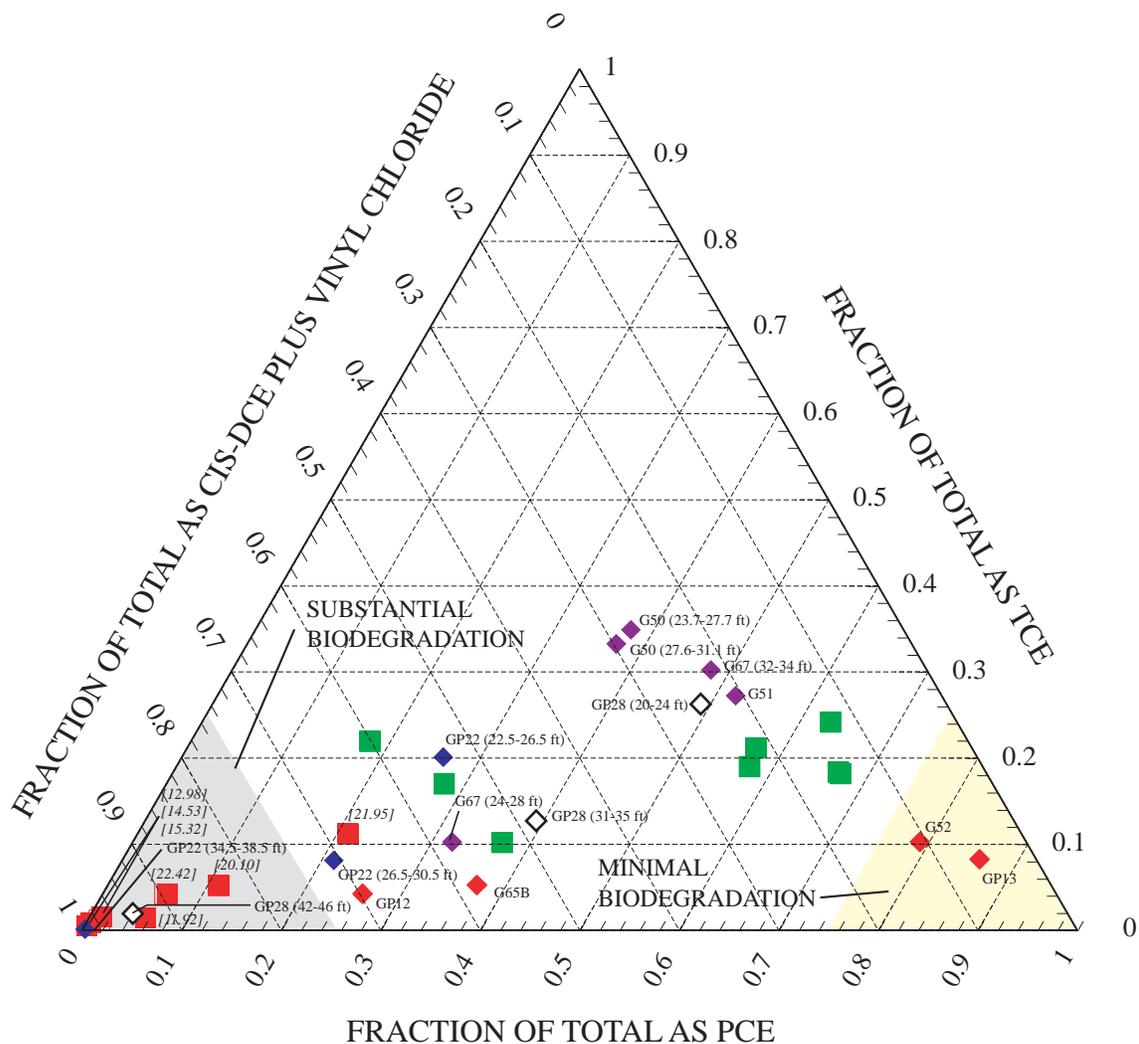
Figure 4-32. Vertical distribution of estimated concentrations of tetrachloroethene (PCE) and other volatile organic compounds (VOCs) in drill cutting samples from bedrock monitoring wells in the vicinity of Operable Units OU1 and OU3. Concentrations estimated using a portable gas chromatograph (GC) [modified from the U.S. Environmental Protection Agency (2001)].



DEPTH OF BOTTOM OF SAMPLING INTERVAL (FEET BELOW THE LAND SURFACE)

- ◆ 0 TO 5 FEET
- 5 TO 10 FEET
- 10 TO 15 FEET
- ▲ 15 TO 31 FEET

Figure 4-33. Tetrachloroethene (PCE) and its common microbial degradation products trichloroethene (TCE) and cis-1,2-dichloroethene (cis-DCE) plus vinyl chloride in OU1 soil samples analyzed by the laboratory. Fractions represent PCE or degradation product concentrations expressed as percent of the total concentration (in millimoles) of chlorinated ethenes (PCE plus TCE plus cis-DCE plus vinyl chloride).



MONITORING WELL OF TEMPORARY WELL SCREEN INSTALLATION

Value in parenthesis indicates the depth interval of the temporary well screen
 Value in brackets indicates the depth to the static water level in monitoring well TW-G at the time of sampling

- ◆ GP12, GP13, G52, G65B
- ◆ GP22
- ◆ G50, G51, G67
- ◇ GP28
- MONITORING WELL TW-C
- MONITORING WELL TW-G

Figure 4-34. Tetrachloroethene (PCE) and its common microbial degradation products trichloroethene (TCE) and cis-1,2-dichloroethene (cis-DCE) plus vinyl chloride in selected ground-water samples from OU1. Fractions represent PCE or degradation product concentrations expressed as percent of the total concentration (in millimoles) of chlorinated ethenes (PCE plus TCE plus cis-DCE plus vinyl chloride). Concentrations from laboratory analysis except for samples from locations GP12, GP13, and G52 which were estimated by the portable gas chromatograph (GC).

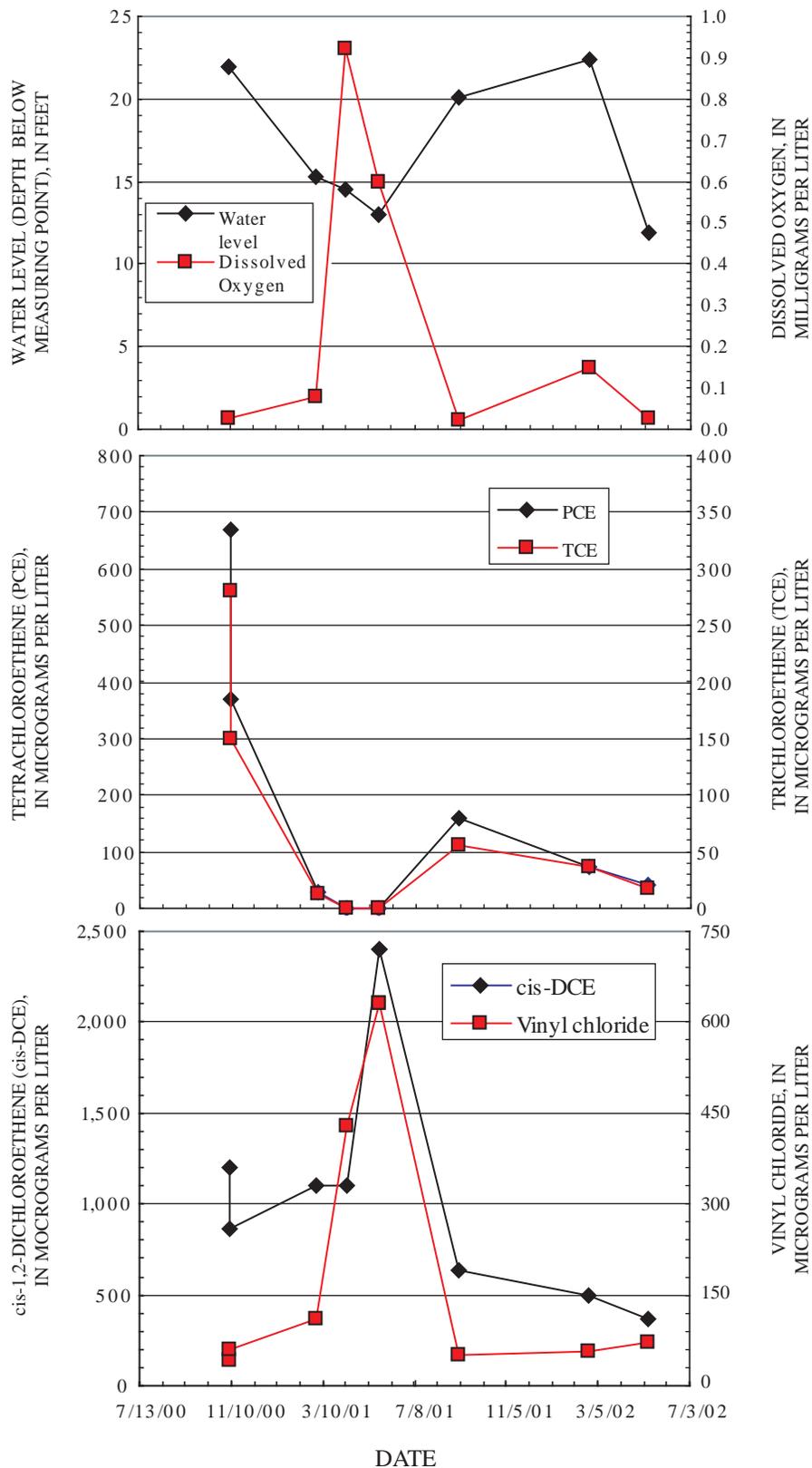


Figure 4-35. Variation in water level and concentrations of tetrachloroethene (PCE) and its degradation products with time in samples from monitoring well TW-G.