Fw: CCP draft report

Scott Miller to: Debbie Jourdan 02/04/2011 11:55 PM

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Debbie,
Can you please save this to the Capital City Plume SDMS file?
Thanks,
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----- Forwarded by Scott Miller/R4/USEPA/US on 02/04/2011 11:50 PM -----

From: James E Landmeyer <jlandmey@usgs.gov>
To: Scott Miller/R4/USEPA/US@EPA
Date: 01/14/2011 02:04 PM
Subject: CCP draft report

Hi Scott,

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Looking forward to hearing some feedback on the draft report....

Jim

____
James E. Landmeyer, Ph.D.
U.S. Geological Survey

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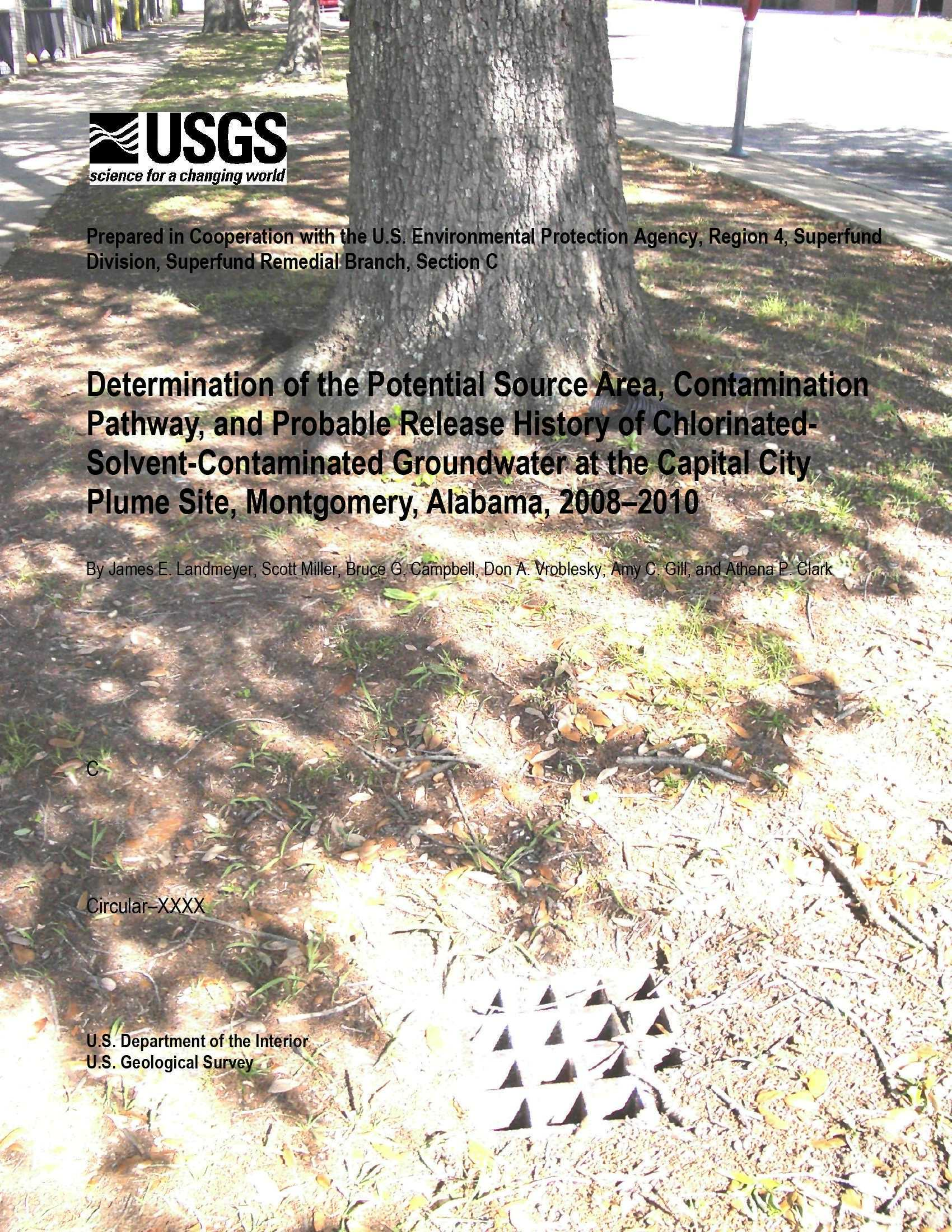

Prepared in Cooperation with the U.S. Environmental Protection Agency, Region 4, Superfund Division, Superfund Remedial Branch, Section C

Determination of the Potential Source Area, Contamination Pathway, and Probable Release History of Chlorinated-Solvent-Contaminated Groundwater at the Capital City Plume Site, Montgomery, Alabama, 2008–2010

By James E. Landmeyer, Scott Miller, Bruce G. Campbell, Don A. Vroblesky, Amy C. Gill, and Athena P. Clark

C

Circular–XXXX

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Conversion Factors

Inch/Pound to SI

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter (cm)
inch (in.)	25.4	millimeter (mm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
yard (yd)	0.9144	meter (m)
	Area	
acre	4,047	square meter (m^2)
acre	0.4047	hectare (ha)
acre	0.4047	square hectometer (hm^2)
acre	0.004047	square kilometer (km^2)
square foot (ft^2)	929.0	square centimeter (cm^2)
square foot (ft^2)	0.09290	square meter (m^2)
square inch (in^2)	6.452	square centimeter (cm^2)
section (640 acres or 1 square mile)	259.0	square hectometer (hm^2)
square mile (mi^2)	259.0	hectare (ha)
square mile (mi^2)	2.590	square kilometer (km^2)
	Volume	
million gallons (Mgal)	3,785	cubic meter (m^3)
cubic inch (in^3)	16.39	cubic centimeter (cm^3)
cubic inch (in^3)	0.01639	cubic decimeter (dm^3)
cubic inch (in^3)	0.01639	liter (L)
	Flow rate	
acre-foot per day (acre-ft/d)	0.01427	cubic meter per second (m^3/s)

acre-foot per year (acre-ft/yr)	1,233	cubic meter per year (m^3/yr)
acre-foot per year (acre-ft/yr)	0.001233	cubic hectometer per year (hm^3/yr)
foot per second (ft/s)	0.3048	meter per second (m/s)
foot per minute (ft/min)	0.3048	meter per minute (m/min)
foot per hour (ft/hr)	0.3048	meter per hour (m/hr)
foot per day (ft/d)	0.3048	meter per day (m/d)
foot per year (ft/yr)	0.3048	meter per year (m/yr)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)
cubic foot per second per square mile [(ft^3/s)/mi^2]	0.01093	cubic meter per second per square kilometer [(m^3/s)/km^2]
cubic foot per day (ft^3/d)	0.02832	cubic meter per day (m^3/d)
gallon per minute (gal/min)	0.06309	liter per second (L/s)
gallon per day (gal/d)	0.003785	cubic meter per day (m^3/d)
gallon per day per square mile [(gal/d)/mi^2]	0.001461	cubic meter per day per square kilometer [(m^3/d)/km^2]
million gallons per day (Mgal/d)	0.04381	cubic meter per second (m^3/s)
million gallons per day per square mile [(Mgal/d)/mi^2]	1,461	cubic meter per day per square kilometer [(m^3/d)/km^2]
inch per hour (in/h)	0 .0254	meter per hour (m/h)
inch per year (in/yr)	25.4	millimeter per year (mm/yr)
mile per hour (mi/h)	1.609	kilometer per hour (km/h)
	Pressure	
atmosphere, standard (atm)	101.3	kilopascal (kPa)
bar	100	kilopascal (kPa)
inch of mercury at 60ºF (in Hg)	3.377	kilopascal (kPa)
pound-force per square inch (lbf/in^2)	6.895	kilopascal (kPa)
pound per square foot (lb/ft^2)	0.04788	kilopascal (kPa)
pound per square inch (lb/in^2)	6.895	kilopascal (kPa)
	Density	
pound per cubic foot (lb/ft^3)	16.02	kilogram per cubic meter (kg/m^3)
pound per cubic foot (lb/ft^3)	0.01602	gram per cubic centimeter (g/cm^3)
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day (m/d)
	Hydraulic gradient	
foot per mile (ft/mi)	0.1894	meter per kilometer (m/km)
	Transmissivity*	

foot squared per day (ft^2/d)	0.09290	meter squared per day (m^2/d)

Temperature in degrees Celsius (°C) may be converted to degrees Fahrenheit (°F) as follows:

°F=(1.8×°C)+32

Temperature in degrees Fahrenheit (°F) may be converted to degrees Celsius (°C) as follows:

°C=(°F-32)/1.8

Vertical coordinate information is referenced to the insert datum name (and abbreviation) here for instance, "North American Vertical Datum of 1988 (NAVD 88)."

Horizontal coordinate information is referenced to the insert datum name (and abbreviation) here for instance, "North American Datum of 1983 (NAD 83)."

Altitude, as used in this report, refers to distance above the vertical datum.

*Transmissivity: The standard unit for transmissivity is cubic foot per day per square foot times foot of aquifer thickness [$(ft^3/d)/ft^2$]ft. In this report, the mathematically reduced form, foot squared per day (ft^2/d), is used for convenience.

Specific conductance is given in microsiemens per centimeter at 25 degrees Celsius (µS/cm at 25 °C).

Concentrations of chemical constituents in water are given either in milligrams per liter (mg/L) or micrograms per liter (µg/L).

NOTE TO USGS USERS: Use of hectare (ha) as an alternative name for square hectometer (hm^2) is restricted to the measurement of small land or water areas. Use of liter (L) as a special name for cubic decimeter (dm^3) is restricted to the measurement of liquids and gases. No prefix other than milli should be used with liter. Metric ton (t) as a name for megagram (Mg) should be restricted to commercial usage, and no prefixes should be used with it.

Determination of the Potential Source Area, Contamination Pathway, and Probable Release History of Chlorinated-Solvent-Contaminated Groundwater at the Capital City Plume Site, Montgomery, Alabama, 2008–2010

By James E. Landmeyer[1], Scott Miller[2], Bruce G. Campbell[1], Don A. Vroblesky[1], Amy C. Gill[3], and Athena P. Clark[3]

Abstract

Detection of the organic solvent perchloroethylene (PCE) in a shallow public-supply well in 1991 and exposure of workers in 1993 to solvent vapors during excavation activities to depths near the water table provided evidence that shallow groundwater beneath the Capital City of Montgomery, Alabama was contaminated. Investigations conducted by state and federal agencies from 1993 to 1999 confirmed the detection of PCE in shallow groundwater, as well as the detection of the organic solvent trichloroethylene (TCE) and various metals, but the source of the groundwater contamination was not determined. In May 2000 the United States Environmental Protection Agency (USEPA), Region 4, Superfund Division, proposed that the site, called the Capital City Plume (CCP)

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[1] U.S. Geological Survey, Columbia, South Carolina
[2] U.S. Environmental Protection Agency, Region 4, Atlanta, Georgia
[3] U.S. Geological Survey, Montgomery, Alabama

Site, be a candidate for the National Priorities List. Numerous site-investigation activities conducted between 2000 and 2007 also did not determine the source of the groundwater contamination.

In 2008, the USEPA, Region 4, Superfund Division, in cooperation with the U.S. Geological Survey Alabama and South Carolina Water Science Centers conducted additional assessments at the CCP Site to determine the potential source area, contamination pathway, and the probable release history of the solvent-contaminated groundwater. The assessments included the collection of (1) passive-diffusion bag samples from the hyporheic zone of Cypress Creek, a tributary to the Alabama River and is located topographically and hydrologically downgradient of the CCP Site and receives shallow groundwater discharge, (2) tissue samples collected in 2008 and 2009 from trees growing in areas in downtown Montgomery characterized by groundwater contamination and from riparian zones along the Alabama River and Cypress Creek, (3) groundwater samples in 2009 analyzed for concentrations of organic and inorganic constituents and groundwater samples in 2010 for concentrations of sulfur hexafluoride and chlorofluorocarbons, and (4) maps of land uses since 1842 within the CCP Site. The data collected were used to (1) determine the potential source area of contaminants detected in groundwater, (2) determine the pathway of groundwater contamination, and (3) determine constraints on the probable contaminant-release history.

The data collected between 2008 and 2010 at the CCP Site as part of these additional assessments indicate that PCE- and TCE-contaminated groundwater beneath the City of Montgomery most likely resulted from (1) the past use of chlorinated solvents and metals by a major commercial printing industry located in downtown Montgomery, (2) the disposal of industrial-trade wastewater that contained these solvents and metals into the sanitary sewer and stormwater systems and recharged shallow groundwater downgradient from the release area after infiltration through pipe joints and(or) leaks, and (3) these activities occurred between the 1940s and 1970s. The data also indicate that a source of PCE and TCE contamination exists in the shallow subsurface near the original release area in downtown Montgomery and that PCE and TCE have be transported to deeper parts of the shallow aquifer.

Introduction

The Capitol City Plume (CCP) Site is characterized by shallow groundwater contamination beneath a widespread area of downtown Montgomery, Alabama. The primary contaminant is perchloroethylene (PCE), but other volatile organic compounds (VOCs), such as trichloroethylene (TCE), and metals, such as chromium, have been detected (Black and Veatch 2002; Malcolm Pirnie 2003; Alabama Department of Public Health 2004; Hall 2007). Perchloroethylene is of concern because it was detected at 7.1 micrograms per liter (µg/L) in a Montgomery public supply well in 1991 and at 160 µg/L in 2009—each detection being above the PCE maximum contaminant level (MCL) of 5 µg/L. Perchloroethylene was synthesized as early as 1821, but widespread usage to meet industrial needs for an effective solvent with the property of decreased flammability did not start until after the 1940s (U.S. Environmental Protection Agency 2000). Perchloroethylene can cause various human health problems ranging from dizziness and headaches to death (Agency for Toxic Substances and Disease Registry 1997). The organic solvent TCE was synthesized in the 1920s and also is used as a non-flammable solvent. The primary metal of concern in groundwater at the CCP Site is chromium (Black and Veatch 2002; Malcolm Pirnie 2003; Alabama Department of Public Health 2004; Hall 2007) although chromium has not been detected in any public supply well above the MCL of 100 µg/L.

Previous investigations between 1991 and 2008 to delineate the groundwater contamination at the CCP Site did not identify the source of the contamination. In 2008, the U.S. Environmental Protection Agency (USEPA), Region 4, Superfund Division, in cooperation with the U.S. Geological

Survey (USGS) Alabama and South Carolina Water Science Centers conducted additional assessments to determine the potential source area, contamination pathway, and the probable release history of the organic and inorganic contaminants in groundwater at the CCP Site. The assessments included the collection of:

(1) Passive-diffusion bag (PDB) samples from the hyporheic zone of Cypress Creek, a tributary to the Alabama River and is located topographically and hydrologically downgradient of the CCP Site and receives shallow groundwater discharge
(2) Tissue samples in 2008 and 2009 from trees growing in downtown Montgomery above areas characterized by groundwater contamination and samples from trees in the riparian zones along the Alabama River and Cypress Creek
(3) Groundwater samples collected in 2009 for concentrations of organic and inorganic contaminants and in 2010 for sulfur hexafluoride (SF_6) and chlorofluorocarbons (CFCs), and
(4) Maps of land uses since 1842 within the CCP Site.

The data collected were used to:

(1) Determine the potential source area of contaminants detected in groundwater
(2) Determine the pathway of groundwater contamination, and
(3) Determine constraints on the probable contaminant-release history.

This report documents the data-collection efforts and presents the results of the potential source area, contaminant pathway, and the probable release history at the CCP Site.

Purpose and Scope

This report describes additional assesement activities made to determine the potential source area, contamination pathway, and the probable release history of chlorinated-solvent contaminated groundwater at the CCP Site in downtown Montgomery, Alabama. These assessments were performed by the Alabama and South Carolina Water Science Centers of the USGS during 2008–2010 in cooperation with the USEPA, Region 4, Superfund Division.

A variety of methods were used during these additional assessments. In August 2008, three PDB samplers were installed in the hyporheic zone of Cypress Creek and analyzed for the presence of organic contaminants, and cores were collected from 69 trees growing in and around downtown Montgomery and analyzed for the presence of organic and inorganic contaminants that had been detected in groundwater. Results from this initial sampling event were used to further characterize the extent of subsurface contamination as had been previously defined since 1991 by traditional methods of sampling monitoring wells. In January 2009, additional cores were collected from trees characterized in August 2008 by organic and inorganic contaminants, and the annual growth rings analyzed for the time-series distribution of metals. In April–May 2009 thirteen existing monitoring wells in downtown Montgomery were sampled for VOCs and metals, and in April 2010 these wells were sampled for SF_6 and CFCs to determine the recharge-age of groundwater across the CCP Site. Histrical maps of the City of Montgomery were used to indicate the spatial and temporal distribution of past land-use activities since 1842 within the CCP Site that may have used chemicals detected in groundwater. All methods used are applicable to other NPL or Superfund sites characterized by long-term groundwater contamination with unknown source areas, contamination pathways, or release histories. Moreover, the multiple line-of-evidence approach strengthens the results of these additional assessments by decreasing the uncertainty inherent to individual methods.

Description of Study Area

The City of Montgomery is located in the northern part of the Eastern Gulf Section of the Coastal Plain Physiographic Province (Figure 1). The City, incorporated on December 3, 1819, is located on a bluff near a sharp meander of the Alabama River. The bluff is composed of, in ascending order, Upper Cretaceous and younger sands and clays up to 260 feet (ft) above the current channel position of the Alabama River, and was created during the Quaternary by the downcutting ancestral Alabama River as it adjusted to lower sea levels (Robinson 2002).

Figure 1. Location of Montgomery County, the City of Montgomery, the Capital City Plume (CCP) Site, and existing public supply and shallow (S) and intermediate (I) monitoring wells related to the CCP Site (modified from Robinson 2002).

The formations that characterize the subsurface geology beneath the City of Montgomery, Alabama include surficial sediments of the Quaternary age ontop of sediments of Upper Cretaceous age ontop of Pre-Cretaceous crystalline rock (Figure 2; Knowles and others 1963; Robinson 2002). The Quaternary and younger-age sediments include the alluvial sediment and terrace deposits of gravel, sand, and clay to depths between 30 and 100 ft below land surface (bls) in the CCP Site study area. Beneath these sediments are the Upper Cretaceous age sediments of the Eutaw Formation at depths between 0 and 400 ft bls because part of the Eutaw Formation is exposed in downtown Montgomery;

most of the Eutaw Formation, however, is covered by younger terrace deposits. The Eutaw Formation rests unconformably on the Gordo Formation. The Gordo Formation outcrops in the bluffs along the Alabama River or is covered by Quaternary terrace deposits. The Gordo Formation unconformably overlies the Coker Formation. The top of the Coker Formation is about 500 to 700 ft bls around the City of Montgomery (Knowles and others 1963). The Coker Formation unconformably overlies pre-Cretaceous crystalline rocks comprised of schist and gneiss.

Figure 2. Generalized stratigraphy and hydrogeologic units underlying Montgomery, Alabama and the Capital City Plume (CCP) Site (modified from Robinson 2002).

The Quaternary and younger-age sediments and the upper permeable sediments of the Eutaw Formation yield water to wells screened to depths between 50 and 90 ft bls and are used for public supply in Montgomery. These sediments are considered the shallow aquifer (Eutaw aquifer) in Montgomery, as wells screened in both sediments have similar water-level elevations (Scott and others 1987; Robinson 2002; Figure 2). In general, the depth to the water table in the shallow aquifer is about 35 ft bls near the PCE-contaminated public supply wells and about 55 ft bls in downtown Montgomery upgradient of the location where workers were exposed to solvent vapors during excavation in 1993 near the water table. Most of the CCP Site shallow monitoring wells installed as part of previous investigations are screened in these shallow-aquifer sediments (Black & Veatch 2002). Some monitoring wells within the CCP Site study area are screened between 150 to 240 ft bls across deeper parts of the shallow aquifer in the Eutaw Formation; these were called intermediate wells in previous reports (Black & Veatch 2002) and the terminology continued in this current report. The Coker Formation also yields water to municipal wells in Montgomery, but wells drilled to the Coker

Formation also are screened in the shallower Gordo and Eutaw Formations; these sediments are called the deep aquifer (Knowles and others 1963). The crystalline rocks are considered relatively impermeable and not tapped by municipal wells in the CCP Site area.

The shallow and deep aquifers have been used since the 1880s by the City of Montgomery for water supply. The Montgomery Water Works and Sanitary Sewer Board (MWWSSB) has two well fields, the north field and west fields. For at least one hundred years groundwater from these wells was the sole source of water for Montgomery. During the 1980s, surface-water resources began to be used and the wellfields supplied no more than 34% of the city's demands. Since about 1997, the MWWSSB has relied almost exclusively on the Alabama and Tuscaloosa Rivers for water supply with supplemental supplies from groundwater from the west wellfield during peak demand and droughts.

Recharge to the shallow aquifer in the CCP Site study area occurs by precipitation, which averages about 55 inches per year (in./y; Robinson 2002). Groundwater in the shallow aquifer flows north toward the Tallapossa River and west toward the Alabama River (Hall 2007). Areas that receive recharge also are potentially susceptible to contamination—areas along the Alabama River flood plain (such as Montogmery) are "especially highly susceptible to contamination from the surface" (Scott and others 1987).

Figure 3. Location of existing public supply wells and shallow (S) and intermediate (I) monitoring wells and generalized groundwater-flow direction at the Capital City Plume (CCP) Site, July 2007, Montgomery, Alabama (modified from Hall 2007).

Previous Investigations

Multiple investigations have been performed at the CCP Site since 1991 following the detection of PCE in a public supply well (Table 1). These initial investigations helped to delineate the extent of groundwater contamination. Because some data generated during these previous investigations are used to support conclusions made from data collected during the additional assessments conducted by the USEPA and USGS during 2008–2010, a brief review is warranted.

Table 1. Timeline of previous investigations and events important to the additional assessments of the Capital City Plume (CCP) Site, Montomery, Alabama, 1819–2010.

In April 1991, the MWWSSB sampled public supply wells in Montgomery pursuant to the USEPA's Wellhead Protection Program. Groundwater from public supply well 9 West (9W; Figure 1) contained 7.1 µg/L PCE and exceeded the National Primary Drinking Water Standard (NPDWS) MCL of 5 µg/L. Well 9W is screened from 69 to 79 ft bls in the shallow aquifer and was in use since 1962. In May 1992, wells 9W and 9 East (9E) both contained 21 µg/L PCE; well 9E is screened from 64 to 74 ft bls in the shallow aquifer and also was drilled in 1962. Well 9W was shut down in 1992 as a result of the PCE detection, and well 9E was shut down in 1997 due to structural problems and PCE detection.

In September 1993, workers excavating soil from about 25 ft bls (slightly above the average depth to water table at that time) to construct the Alabama Retirement Systems Administration (RSA) Energy Plant on the corner of Monroe and McDonough Streets were overcome by acute exposure to vapors later determined to be PCE and possibly TCE (Black & Veatch 2002). The excavation site is located about 2,280 ft topographically and hydrologically upgradient of PCE-contaminated public supply wells 9W and 9E. In response to this acute exposure, the Alabama Department of Environmental Management (ADEM) conducted Phase I and Phase II investigations at the excavation site in October and November 1993, respectively. During Phase I, soil samples were collected in the RSA Energy Plant area and groundwater samples were collected from a shallow (S) monitoring well (MW) near the excavation (MW-1S) and analyzed for PCE and TCE (Figure 4). During Phase II, three additional monitoring wells were installed (MW-2S, -3S, and -4S) near the excavation area, and soil-gas samples were collected and analyzed using the PETREX™ tube method (Black & Veatch 2002). PCE- and TCE-contaminated soil was identified, removed, and disposed of between 1993 and 1994. During the Phase I and Phase II investigations, no obvious source of the PCE or TCE was observed (Black & Veatch 2002).

Figure 4. Locations of existing monitoring wells and the approximate extent of the Capital City Plume (CCP) Site as defined by PCE in groundwater, October 15, 1993. All monitoring wells are shown but not necessarily available for sampling in 1993 (data from Black & Veatch 2002).

In February 1995, ADEM inititated a Preliminary Assessment (PA) in accordance with the CERCLA, or Superfund, regulations. Several temporary monitoring wells were installed and samples confirmed that PCE and TCE were present in deep soil and groundwater in parts of downtown Montgomery near the RSA Energy Plant. In 1996, the RSA Tower was built west of and adjacent to the Energy Plant site. At that time, ADEM recommended that the CCP Site be considered for the NPL.

In 2000, pursuant to CERCLA regulations, the USEPA initiated a Remedial Investigation (RI) to collect additional data to evaluate the extent of groundwater contamination at the CCP Site (Black &

Veatch 2002). A total of sixteen permanent and sixteen temporary monitoring wells were installed in the City of Montgomery using vibracore drilling technology. Most of the wells were installed adjacent to the RSA Energy Plant, near the contaminated public supply wells, and between these locations of known contamination; one well was located upgradient of the Energy Plant to represent background conditions. Thirteen of the sixteen permanent wells consisted of a pair of wells screened to the shallow and intermediate parts of the shallow aquifer. Samples of soil and aquifer sediment were collected during well-drilling activities and screened in the field for the presence of organic contamination by using a hand-held total-gas detector with photo-ionization detection (PID). During well drilling, little visible contaminantion was evident from the soil samples retrieved and investigators concluded a source of PCE in the soil zone did not exist at the well-installation locations (Black & Veatch 2002). Slug tests were performed in the completed monitoring wells and used to determine the hydraulic conductivity of the shallow and intermediate aquifers. The groundwater flow rate in the shallow aquifer was determined to be about 100 feet per year (ft/y) (Black & Veatch 2002). The wells were sampled in May 2000 and indicated PCE and TCE contamination (Figure 5). In early 2000 the USEPA proposed to list the CCP Site on the NPL (Federal Register, May 11, 2000) because public supply wells had PCE at concentrations greater than the MCL and the source area, contamination pathway, and release history of the PCE were unknown.

Figure 5. Locations of existing monitoring wells and the approximate extent of the Capital City Plume (CCP) Site as defined by PCE in groundwater, May 2000 (modified from data from Black & Veatch 2002).

The USEPA collected additional soil samples at the RSA Tower and Energy Plant area in 2001. Results of these samples supported previous observations of a lack of an obvious source of PCE contamination (Figure 6). In 2002 ADEM collected six water samples from Cypress Creek—one surface-water sample collected near the confluence with the Alabama River contained PCE at 7.2 µg/L (Black & Veatch 2002). In 2002, chromium was detected in 55 of 66 groundwater samples collected at the site, although little to no chromium was detected in soil samples (Black & Veatch 2002).

Figure 6. Locations of existing monitoring wells and the approximate extent of the Capital City Plume (CCP) Site as defined by PCE in groundwater, January 2001 (modified from data presented in Black & Veatch 2002).

In 2003 the City of Montgomery initiated a Feasibility Study (FS) at the CCP Site (Malcolm Pirnie, Inc. 2003). Also in 2003, an Environmental Site Assessment (ESA) was made on behalf of the Montgomery County Commission prior to the purchase of a piece of property located on Washington Avenue, because the property was located within the CCP Site boundary. As part of the ESA, soil samples were collected from temporary borings, the samples screened in the field for organic contamination by using a hand-held total-gas detector with a PID, and temporary wells were installed and sampled (EMC, Inc. 2003). Soil and groundwater samples characterized by high PID readings were sent to a laboratory for analysis but no samples exceeded the method detection limit for PCE, benzene, toluene, ethylbenzene, and xylenes (BTEX) and methyl *tertiary*-butyl ether (MTBE). The source of the high PID readings, however, was not further investigated.

In 2007, the City of Montgomery conducted a groundwater monitoring event of the existing USEPA wells (Hall 2007). PCE and TCE continued to be detected in wells that previously had PCE and TCE, and chromium also was detected (Figure 7).

Figure 7. Locations of existing monitoring wells and the approximate extent of the Capital City Plume (CCP) Site as defined by PCE in groundwater, July 2007 (modified from Hall (2007)).

In August 2008, the South Carolina and Alabama Water Science Centers of the USGS in cooperation with the USEPA, Region 4, Superfund Division, started additional assessments at the CCP Site to determine the potential source area, contamination pathway, and probable release history.

Acknowledgments

The authors thank Mr. Rusty Kestle, USEPA, formerly of ADEM, who assisted with field work at the CCP Site during August 2008 and who, in 1993, correctly commented that additional groundwater sampling would be necessary to fully understand the extent and history of the groundwater contamination at the CCP Site; Mr. Thomas R. "Buddy" Morgan, General Manager, Montgomery Water Works & Sanitary Sewer Board for his insight to the history of the santitary sewer and stormwater systems in downtown Montgomery; the (late) Mr. Kenneth J. Groves, Jr., former Director, Planning and Development, City of Montgomery; Mr. Russell Stringer, Urban Forester, City of Montgomery; Mr. Elliott Jones, USGS Georgia Water Science Center, for his help with field work in August 2008; Mr. Will S. Mooty and Mr. Richard S. Moreland, USGS, Alabama Water Science Center, for their help during groundwater-sample collection efforts in 2009 and 2010; and to the citizens of Montgomery that expressed interest and showed hospitality during our time in Montgomery.

Methods

Multiple methods were used to determine the potential source area, contamination pathway, and probable release history at the CCP Site. Most of the methods employed had not been used previously at the CCP Site and were selected to provide data to help answer the following questions that had remained unanswered at the CCP Site since 1991;

(1) What is the potential source area of the PCE- and TCE-contamination in groundwater?
(2) What is the predominant pathway that resulted in groundwater contamination?
(3) When did the release and subsequent groundwater contamination occur?

Initial site-assessment activites began in August 2008 and used standard tree-core collection methods to collect cores from 69 trees growing in and around downtown Montgomery. These cores were analyzed in the field immediately after collection for the presence of organic contaminants and samples were analyzed in a laboratory for the presence of inorganic contaminants. Results of the organic contaminants detected in the tree cores were used to confirm or refine the extent of soil and groundwater contamination delineated during previous investigations. Three PDB samplers also were deployed in the hyporheic zone of Cypress Creek during the tree-core sampling event and analyzed for organic contaminants using the same method as for the tree cores. In January 2009, additional tree cores were collected from trees identified in 2008 to be characterized by high concentrations of metals, such as chromium and chloride. Annual growth rings, or sections of tree-cores comprised of multiple adjacent annual growth rings, were analyzed for inorganic contaminants by proton-induced X-ray emission (PIXE) analyses to determine the spatial and temporal distribution of metals. In April–May 2009 thirteen existing monitoring wells in downtown Montgomery were sampled for VOCs and metals, and in May 2010 samples of groundwater were analyzed for concentrations of SF_6 and CFCs and used to determine the age of groundwater since recharge and, therefore, help to establish the probable release history of the groundwater contamination. Historical maps of the City of Montgomery since 1842 were examined relative to the distribution of groundwater contamination to determine potential source areas. Because the City of Montgomery is an active metropolitan area, the site-assessment methods were selected to be as minimally invasive or disruptive as practicable. The methods used are transferrable to other NPL or Superfund sites characterized by groundwater contamination with unknown source areas or release histories.

Determination of the Potential Source Area and Contamination Pathway

One obstacle that inhibited the ability of previous investigators to determine the source area of PCE-contaminated groundwater detected between 1991 and 1993 was the singular absence of PCE-contaminated soils near land surface. Source-area determination was further complicated by the presence of (1) multiple past and current potential industrial or commercial sources of PCE within the City of Montgomery; (2) multiple land uses within the City of Montgomery since its beginning in 1819, and (3) a lack of records documenting the usage and disposal of hazardous materials prior to the 1980s.

Tree-Core Survey

In general, trees can be used to assess the distribution of subsurface contamination because tree roots interact with soil gas, soil moisture, and groundwater (Landmeyer 2001; Landmeyer and others 2001; Vrobleksy 2008; Landmeyer *in press*). Downtown Montgomery is characterized by landscape trees on City-owned properties such as sidewalks and are managed by Mr. Russell Stringer, the Urban

Forester of Montgomery. The trees include laurel oak (*Quercus laurifolia*), live oak (*Quercus virginiana*), red oak (*Quercus ruba*), water oak (*Quercus nigra*), maple (*Acer rubrum*), ginko (*Ginko biloba*) and magnolia (*Magnolia grandiflora*) and range from about ten to more than 100 y old. The grid-like distribution of city blocks and trees that overlie the groundwater contamination provided an objective approach to guide the collection of tree cores for contaminant assessment (Figure 8).

Figure 8. Grid system to guide tree-core collection in downtown Montgomery. These blocks selected for tree-core sampling are located within the City of Montgomery's local groundwater drainage basin as inferred from topographical highs.

Within the CCP Site, 69 trees were cored from landscape vegetation in and around downtown Montgomery (Figure 9). Most of the trees cored were relatively young (< 50 y) but a few were greater than 100 y. Not all blocks were included in the survey; some blocks had no trees, or had trees but could not be cored as they were located on private or state property, or trees were not cored at the request of the Urban Forester (Figure 9). Native vegetation growing in the riparian zones of the Alabama River and Cypress Creek, such as sycamore (*Platanus occidentalis*) and cottonwood (*Populus heterophylla*) also were sampled—these trees were some of the largest and oldest trees sampled during the tree-core survey. Before core collection began, general information about each tree, such as genus, species, and diameter at breast height (dbh) was documented and the location of each tree mapped with a handheld global positioning system (GPS).

Figure 9. Locations of trees core for volatile organic compounds (VOCs) and metals analysis in August 2008. Also shown are the locations of the three Passive Diffusion Bag samplers in Cypress Creek.

All tree cores were collected using standard forestry practices with an increment auger (Phipps, 1985; Landmeyer 2001;Vrobleksy 2008) and analyzed for the presence or absence of organic and inorganic compounds detected in groundwater, such as PCE, TCE, and metals. In brief, tree-core samples were collected at breast height from the southern side of each tree. A core consists of at least a 2-inch (in.) long cylinder-shaped piece of tissue that included the xylem (the water-transmitting part of the tree) and bark and represents a composite of the most recent annual growth rings. The core barrel was flame sterilized between sample collection. Cores were transferred as quickly as possible to 40-millileter (mL) volatile organic analysis (VOA) glass vials, capped with a screw-on septated cap with a Teflon liner to minimize contaminant loss by volatization, and then stored on ice. Tree cores were analyzed for organic compounds by gas chromatography, photo-ionization detection (GC/PID; Photovac 10S Plus) in a hotel room near the sampling area within minutes to one day after core collection. The method reporting level (MRL) for PCE, TCE, *cis*-1,2-DCE, and benzene was 2, 10, 15, and 10 parts per billion by volume (ppbv), respectively (Vroblesky 2008). To increase contaminant volatilization into the vial headspace prior to GC/PID analysis, the vials were preheated in a microwave for between 15 and 60 sec as described in Vroblesky and others (2009). A similar tree-core collection method had been used successfully by the USGS at a Superfund site in Missouri as part of an assessment of subsurface contamination by chlorinated solvents (Schumacher and others 2004).

The three PDB samplers were installed less than 1 ft into the bed sediment of Cypress Creek (Figure 9). The PDB sampler consisted of a 40 mL VOA vial wrapped in plastic (Church and others 2002). After exposure to the porewater in the bed sediment for no more than 6 hours (h), the PDB samplers were retrieved, capped with a screw-on septated cap with a Teflon liner and analyzed as described above.

A subset of tree cores was shipped overnight to a contract laboratory (Elemental Analysis Incorporated (EAI)) for analysis of inorganic constituents by PIXE. Each core was prepared into a sample with a thickness greater than 80 microns for thick-target analysis by PIXE. Tree-core analysis for inorganics has been done for many years and is applicable for most elements in trees (Lewis 1995). Tree cores representative of background conditions of metals for an urban area not characterized by solvent- or metals-contaminated groundwater were collected near the USGS SC Water Science Center in Columbia, SC. The PIXE calibration, accuracy, precision, and detection limits for individual metals are contained in a Quality Assurance Document (EAI 2008).

Groundwater Sampling and Analysis

In April–May 2009, samples were collected from thirteen existing monitoring wells in the vicinity of the CCP Site plume as identified in consultation with the USEPA, Region 4, Superfund Division. Data collected at each well included measurement of the static groundwater-level prior to sample collection and basic water-quality parameters including temperature, pH, dissolved oxygen, and specific conductance during sample collection with a submersible pump and Teflon tubing using low-flow techniques. To reduce the possibility of cross-contamination, the pump was decontaminated after each sample collection, and the Teflon tubing discarded. Groundwater samples were filtered and preserved in the field when required. Groundwater samples were shipped to and evaluated by the USGS National Water Quality Laboratory for concentrations of VOCs and trace metals. Groundwater samples also were collected from the same wells during May 2010 as part of a USEPA-conducted sampling event.

Chloroform Concentrations

All groundwater samples collected in April–May 2009 were analyzed for concentrations of VOCs that included the compound chloroform. In treated (chlorinated) drinking water, chloroform concentrations range from 2 to 44 µg/L (Minear and Amy, 1996). In ambient groundwater in the United States, chloroform is the most frequently detected VOC at a median concentration of 0.08 µg/L (Zogorski and others 2006). This frequency of detection and low concentration in groundwater is primarily the consequence of the almost century-long and widespread usage of the chlorination of drinking-water supplies and wastewater that has now entered the global hydrologic cycle (Zogorski and others 2006; Ivahnenko and Zogorski 2006).

Historical City Maps

The City of Montgomery has a long history and multiple land uses since incorporation on December 3, 1819. Knowledge of past land uses that occurred within the CCP Site where the contaminants detected in groundwater, such as PCE, TCE, and metals, may have been used were used to assist in the determination of potential sources areas. Various types of maps were consulted: USGS topographic maps; historical maps from the University of Alabama Department of Geography; and maps in books about the City of Montgomery. The usefulness of these maps in helping to determine the potential source area is discussed as part of other sections of this report.

Determination of the Probable Release History

The identification of source areas that contribute to groundwater contamination is essential in understanding contaminant-release behavior and to facilitate source-area remediation. Equally important is the determination of when the contaminants were released to the subsurface such that well-informed decisions can be made regarding the time needed for the contaminants to be remediated.

Sulfur Hexafluoride and Chlorofluorocarbon Concentrations

Sulfur hexafluoride is a trace atmospheric gas that has natural and anthropogenic sources. The detection of SF_6 in groundwater indicates the presence of recharge since the 1970s (Busenberg and Plummer 1997; Busenberg and Plummer 2000). Groundwater samples collected by the USEPA and USGS in May 2010 were analyzed for SF_6 concentrations by the USGS Reston Chlorofluorocarbon Laboratory.

The concentrations of the CFCs 1,1,2-trichloro-1,2,2-trifluoroethane (CFC-113) and trichlorofluoromethane (CFC-11) were measured in groundwater samples collected in April–May 2009 and May 2010 for two purposes; (1) to indicate a potential localized industrial source of CFC contamination to groundwater and (2) using ambient, uncontaminated levels of CFCs to indicate the presence of recharge since the 1940s (Plummer and Friedman 1999).

Dendrochemistry

The study of annual growth rings of trees is called dendrochronology, and has been used for almost 100 y (Lewis 1995). Dendrochronology is based on the fact that for most trees, each year of growth is preserved as an annual concentric ring of tissue. Because each growth ring reflects the environmental factors encountered by the tree as it grew, dendrochronological techniques have been used to construct past climate history and water resources (Ferguson and Graybill 1983).

The preservation of environmental factors in each growth ring also has been used at contaminated sites to investigate the interaction of plants with trace metals (Nabais and others 1999; Balouet and others 2009), often referred to as dendrochemistry. Contaminant exposure preserved in annual growth rings can be analyzed to determine the timing of exposure. This approach was used by Vroblesky and Yanosky (1990) who determined when heavy metals had been released to groundwater. Such retrospective analysis was used to understand the interaction of plants with heavy metals such as zinc and lead released to the subsurface (Lewis 1995) and iron to the air (Baes and McLaughlin 1984).

Typically, dendrochemical approaches are not supported for use with organic compounds, because the organic molecules are not preserved in the plant tissue after uptake. Organic compounds that are halogenated, however, such as PCE and TCE, can be used for dendrochemistry because the chlorine substitution is preserved in the tree (Yanosky and others 2001). For all dendrochemical approaches, older annual rings are assumed to have lost biological function and, therefore, preserve trace elements within the ring at levels equal to when the time the element was originally taken up.

The assumption that tree-rings preserve a record of the past uptake of trace elements is not necessarily valid in all cases. Some elements can be translocated after uptake to previously formed rings (Nabais and others 1999). If the concentrations within each ring change over time after uptake, then it complicates the use of these elements to date contaminant releases (Hagemeyer and Schäfer 1995). Hagemeyer and Schäfer (1995) showed considerable season variability for the metals cadmium, lead, and zinc in beech trees, with highest concentrations in rings during dormancy when tree water content is higher than during periods of active growth. Hagemeyer and others (1994) also detected seasonal variations in nickel concentrations in stem wood of beech trees. Baes and McLaughlin 1984) report that aluminum, calcium, copper, manganese, and zinc are not translocated after uptake whereas lead may be (Baes and Ragsdale 1981).

Dendrochemistry was used at the CCP Site to determine when particular trees were exposed to subsurface chlorinated solvents or metals. Trees sampled in August 2008 and determined to contain chlorinated solvents and metals were re-sampled in January 2009 using the same field techniques and analyses by PIXE as previously described. The detection of metals in specifc and datable annual growth rings counting back from the bark was used to constrain probable times of contaminant uptake and, as a consequence, contaminant-release history.

Results and Discussion

Determination of the Potential Source Area and Contamination Pathway

Tree-Core Survey

Organics

The chlorinated solvents PCE, TCE, and *cis*-1,2-dichloroethylene (*cis*-1,2-DCE) were detected in the vial headspace at concentrations above each analytes' MDL for tree cores collected in and around Montgomery and riparian zones (Table 2). The detection of *cis*-1,2-DCE typically indicates the biotransformation of PCE and TCE rather than the release of a separate source of *cis*-1,2-DCE. Of the 69 trees cored in August 2008, TCE was the most frequently detected chlorinated solvent and was found in 33 cores (47%); PCE was the next most frequently detected and found in ten cores (10%); *cis*-1,2-DCE was detected in two cores (2%; Table 2). PCE and TCE were co-detected in six trees, and TCE and *cis*-1,2-DCE were co-detected in two trees; *cis*-1,2-DCE was not detected in any tree that also contained PCE (Table 2).

Table 2. Volatile organic compound (VOC) data for tree cores collected in August 2008.

The highest vial-headspace concentration of PCE was in T32; T32 is located on the same block as the RSA Energy Plant where PCE was first detected in 1993 in soil-gas and groundwater samples. In adjacent T31, PCE and TCE were co-detected. Detection of PCE and TCE in tree cores from this area of known PCE- and TCE-contaminated groundwater validates the use of the tree-core survey approach to detect contaminants in groundwater. The highest vial-headspace concentration of TCE was in T64, located at the western part of the 200 block of Washington Avenue in an area of the CCP Site not previously characterized by TCE contamination. Moreover, T64 had the highest TCE concentration in the vial headspace of a tree core ever measured by the authors. The detection of PCE and TCE in the headspace of vials that contained tree cores from these locations also indicates the presence of

(1) a near-surface residual source of PCE and TCE
(2) a source of PCE and TCE in shallow groundwater, or
(3) a mixture of both sources.

The spatial distribution of PCE, TCE, and *cis*-1,2-DCE detection in the headspace of vials that contained tree cores confirms the distribution of groundwater contamination by these compounds as measured in April 2007 (Figure 10). In general, PCE was detected in cores from trees that grow near or upgradient of monitoring wells that contained PCE in August 2007 (Figure 10). PCE also was detected in cores from trees that grow in areas where no monitoring wells were located but the trees are within the CCP Site boundaries. PCE also was detected in the headspace of vials that contained tree cores in four trees that grow to the west of Washington and Dexter Avenues, in the block of the RSA Tower Energy Plant, near the City waterworks, and the riparian zones of Cypress Creek and the Alabama River (Figure 10).

Figure 10. Locations of tree cored in August 2008 and trees shown that had VOC detections aove the MDL in tree-core headspace. The actual concentrations detected are shown in Table 4. The locations of a major commercial printing industry since 1828 are shown. The detection of TCE in the headspace of vials that contained tree cores that grow upgradient of the location of previously identified TCE groundwater contamination at the RSA Energy Plant provides the first evidence of the existence of an upgradient, near-surface source of TCE located along Washington Avenue. Also shown is the generalized direction of groundwater flow in the shallow aquifer (modified from Hall (2007). TCE and *cis*-1,2-DCE were detected only in PDB1 located downgradient from PCE- and TCE-contaminated wells 9W and 9E.

In general, TCE was detected in cores from trees that grow near or upgradient of monitoring wells that contained TCE in August 2007 (Figure 10). TCE also was detected, however, in cores from multiple trees that grow near or upgradient of wells that did not contain TCE in August 2007 (i.e., MW-9S, -1S, and -5S; Figure 10). TCE also was detected in cores from trees that grow where no monitoring wells are located but the trees are within the CCP Site boundaries. TCE was detected in the headspace of vials that contained cores from four trees that grow along the 200 block of Washington Avenue, even though no TCE was detected in groundwater in July 2007 from nearby MW-9S (Hall 2007). TCE also was detected in the headspace of vials that contained cores from trees that grow along Dexter Avenue;

Monroe Street, McDonough Street, Lawrence Street, and Hult Street, and downgradient in the riparian zones of Cypress Creek and the Alabama River. The trees from which cores had TCE detection had a wider distribution than for PCE. The highest concentration of TCE in the headspace of a vial that contained a tree core was for T64 that grows along Washington Avenue. Depth to groundwater near T64 in MW-9S is about 55 ft bls and, therefore, the detection of TCE in the core indicates that a predominately shallow source of residual TCE exists near depths of the root zone. Moreover, the detection of TCE in the headspace of vials that contained cores from trees that grow upgradient of the location of previously identified TCE groundwater contamination at the RSA Energy Plant provides the first evidence of the existence of an upgradient, near-surface source of TCE located along Washington Avenue (Figure 10).

In general, *cis*-1,2-DCE was detected only in the headspace of vials that contained cores from T64 and from a tree that grows in the riparian area of Cypress Creek; *cis*-1,2-DCE was not detected in the headspace of vials that contained cores from trees that grow near well MW-4S that contained *cis*-1,2-DCE in August 2007, however.

The high tree-core headspace results of TCE for T64 near Washington Avenue shed light on results from two previous investigations within the CCP Site near T64. First, during the USEPA RI in 2000, elevated soil-gas vapors were measured in the field during vibracore well-installation activities for MW-9S and -10S along Washington and Dexter Avenues (Black & Veatch 2002). Soil recovered from above the water table at MW-9S and -10S was characterized by elevated gas measurements (Figure 11). Conversley, elevated gas was detected only after the water table was encountered for soil recovered for downgradient wells MW-4S, -7S, and -8S (Figure 11; Data from Black & Veatch 2002, interpretation by USGS). The elevated soil-gas data for MW-9S and -10S and high tree-core headspace of TCE for nearby tree T64 indicate the presence of a source of near-surface TCE-soil contamination.

Second, in 2003 the Montgomery County Commission had an ESA performed prior to purchasing property located at 200 Washington Avenue, the former location of a major commercial printing industry (CPI) from 1940 to 1997 in downtown Montgomery. The ESA consisted of soil-sample collection and analysis and temporary monitoring-well installation, sampling, and analysis. During the ESA, soil samples collected from near 200 Washington Avenue were screened for VOCs in the field using a hand-held PID. The samples with the highest screening levels were submitted for laboratory analysis of PCE, BTEX, and MTBE. All samples submitted, however, did not exceed the method detection limits for PCE, BTEX, and MTBE of 5 parts per billion (ppb; EMC Inc. 2003). The cause of the high screening levels observed in the field was not further investigated. In light of the high tree-core TCE headspace concentration detected in August 2008 for T64 and T61 near 200 Washington Avenue, the high screening result measured in 2003 may have been caused by TCE.

Figure 11. Cross section showing the PID results for wells installed in 2000 during the USEPA RI and areas where the ESA was performed in 2003 (data from Black & Veatch 2002; data interpretation by USGS).

The detection of PCE, TCE, and *cis*-1,2-DCE in trees cores in areas where the depth to the water table is 35-ft bls or greater and beyond the direct interaction of tree roots indicates that these contaminants are present above the water table in unsaturated sediments. Moreover, the dectections of these contaminants in the tree cores indicate that PCE, TCE, and *cis*-1,2-DCE were present in the subsurface at the time of tree-core collection in August 2008 because the tree-cores analyzed are composed of xylem tissues that contain recently uptaken water and soil gas.

The distribution of trees that contained contaminants in the August 2008 tree-core survey were compared to locations of multiple, historical land-use activities in the CCP Site area since 1842 that could have used these chemicals (Figure 10). Multiple land uses in the CCP Site area that may have used PCE and TCE include dry cleaners, metal shops, gasoline stations, and commercial printing industries (CPI). However, only the CPI has occupied multiple locations across the CCP Site in downtown Montgomery since 1828 and used PCE and TCE. One CPI, a major newspaper manufacturer, has had multiple locations in downtown Montgomery in the CCP Site area from 1833 to 1997 and was located in areas where tree-cores revealed widespread PCE and TCE contamination (Figure 10). Moreover, the location of the CPI between 1940 and 1997 along Washington Avenue represents the only potential upgradient source of the contaminants detected in the adjacent trees and downgradient monitoring wells.

The location of the only PDB sampler (PDB1, Figure 10) in Cypress Creek bed sediments near Court Street that had detections of TCE and *cis*-1,2-DCE and the proximity of PDB1 to the TCE- and PCE-contaminated public-supply wells 9W and 9E indicates that the contamination may be derived from the same source, in this case, a plume of PCE- and TCE-contaminated groundwater. The detection of *cis*-1,2-DCE in the PDB sampler indicates TCE biotransformation under the anoxic hyporheic zone conditions.

Metals

The metals chloride, chromium, lead, sodium, phosphorus, magnesium, sulfur, manganese, iron, copper, zinc, strontium, rubidium, silica, potassium, calcium, aluminum, and nickel were detected above MDLs in seventeen trees selected to represent subsurface conditions across the CCP Site and downgradient riparian zones (Table 3). Each detection represents a composite concentration of the total amount of metal present in the outermost annual growth rings and, therefore, represent the most recent years of growth at the time of core collection in August 2008. Results for the metals detected at higher levels and have potential industrial sources are described in detail.

Table 3. Tree-core inorganic data.

Chloride was detected above the average MDL of 5.95 µg/kg (1 µg/kg is equivalent to 1 part per million (ppm)) in all but four samples (Table 3). The dectection of chloride because elevated levels of chloride could indicate the past or current interaction of trees with chlorinated solvents. Chloride concentration differed widely among trees cored and ranged from 4.0 to 135.4 ppm; the mean was 31.8 ppm (Table 3). Chloride concentrations above the mean were detected in four trees; T23 (maple), T59 (oak), T3 (sycamore), and T35 (oak) (see Figure 9 for locations and Figure 12a for results). These trees with elevated chloride concentration are located downgradient from Washington Avenue where TCE was detected in trees and may indicate, therefore, that the chloride may be from exposure of trees to chlorinated solvents in the subsurface. This same relationship was reported at another study area by Yanosky and others (2001). Of the trees that had high chloride concentrations, TCE was only detected in T3. It is possible that the chloride detected represents a cumulative record of a tree's recent past interaction with chlorinated solvents.

Figure 12. 12a-j. Results of PIXE analysis of metals in tree cores, August 2008. Trees are depicted that had concentrations above the mean concentration reported for each metal.

Sodium was detected above the average MDL of 67.1 ppm in seven samples (Table 3). The sodium concentration was relatively stable among the trees cored, and ranged from 59 to 75 ppm; the mean was 66.8 ppm and the average MDL was 67.1 ppm (Table 3). Comparison of the chloride to sodium ratio (Cl/Na) of the tree cores indicates that the ratio was greater than one for only one sample, that being collected from T23. A ratio greater than one would indicate an imbalance in the sources and sinks of chloride and sodium, such as a source of chloride or sink of sodium. Hence, the high Cl/Na ratio for T23 and its location downgradient from Washington Avenue may indicate that the Cl is from the uptake by the tree of chlorinated solvents.

Chromium was detected above the average MDL of 1.11 ppm in all but six samples (Table 3). The chromium concentrations ranged from 0.78 to 35.2 ppm; the mean was 4.43 ppm (Table 3). The core from T15 (Oak, water) had 35.22 ppm and T17 (Ginko) upgradient of T15 had 6.12 ppm (Figure 12b). Both trees are downgradient from Washington Avenue. The overall lower concentration of chromium in tree cores, relative to chloride and sodium, may be a result of chromium translocation after uptake that is limited to the root zone (Pulford and others 2001), or that chromium uptake occurs until concentrations become toxic, especially for the more mobile form of chromium, hexavalent chromium; Shanker and others 2005; Yu and others 2007).

Lead was detected above the average MDL of 1.56 ppm in all but eight samples (Table 3).The lead concentrations of the trees cored ranged from 1.25 to 2.06 ppm; the mean was 1.56 ppm (Table 3). The overall low concentrations of lead in tree cores can be explained by the fact that the bioavaiability of lead to tree roots is low, especially in the oxic subsurface conditions at the CCP Site, and that lead does not have a vapor phase under near-surface conditions.

Phosphorus was detected above the average MDL of 10.6 ppm in all samples (Table 3). The phosphorus concentrations ranged from 42 to 807 ppm; the mean was 235.5 ppm. Tree cores from T29, T64, T31, T21,and T35 had concentrations above the mean. Magnesium was detected above the average MDL of 45.6 ppm in all samples (Table 3). The magnesium concentrations ranged from 136 to 1,790 ppm; the mean was 523.4 ppm. Tree cores from T32, T29, T25 and T35 had concentrations above the mean. Potassium was detected above the average MDL of 4.94 ppm in all samples (Table 3). The potassium concentrations ranged from 368 to 2,240 ppm; the mean was 1,481.5 ppm. Tree cores from T59, T29, T15, T64, T25, T47, T17, T21, T35, T32, and T62 had concentrations higher than the mean. Calcium was detected above the average MDL of 11.6 ppm in all samples (Table 3). The calcium concentrations ranged from 616 to 6,170 ppm; the mean was 1,841.1 ppm. Tree cores from T31, T44, T17, and T35 were higher than the mean.

Rubidium was detected above the average MDL of 1.87 ppm in all but eight samples (Table 3). The rubidium concentrations in the trees cored varied widely and ranged from 1.50 to 9.00 ppm; the mean was 3.48 ppm. The trees with higher than mean concentrations were T32 (Oak, Live), T29 (Oak, Live),T15 (Oak, Water), T31(Oak, Laurel), T32(Oak, Live), T62(Oak, Live) (Figure 12c). There were as many oaks cored that had lower rubidium concentrations, so the high concentrations is not solely dependent on the species of the tree. Rubidium was used to manufacture inks and paints. The higher concentrations of rubidium were detected in trees that also contained PCE and TCE and located in hot spots of soil and groundwater contamination. The ease of plant uptake of rubidium is shown by the use of a rubidium stable isotope (^{86}Rb) as an analogure to potassium uptake (Jones and others 1987).

Strontium was detected above the average MDL of 2.47 ppm in all but one sample (Table 3). The strontium concentrations in the trees cored varied widely and ranged from 1.90 to 32.70 ppm; the mean was 11.93 ppm. The trees with higher than mean concentrations were T59 (Oak, Laurel), T29 (Oak, Live),T17 (Ginko), T31(Oak, Laurel), T44(Oak, Red), T35(Oak, Laurel) (Figure 12d). There were as many oaks cored that had lower strontium concentrations, so the high concentrations is not solely dependent on the species of tree. Stronium was used to manufacture inks and paints.The higher concentrations of strontium were in trees that contained PCE and TCE (except T35 and T59) and were located in hot spots of soil and groundwater contamination.

Iron was detected above the average MDL of 0.94 ppm in all samples (Table 3). The iron concentrations in the trees cored varied widely and ranged from 53.00 to 538.00 ppm; the mean was 159.08 ppm. The trees with higher than mean concentrations were T32 (Oak, Live), T15 (Oak, Water),T64 (Oak, Laurel), T25(Magnolia), T3(Sycamore), T6(Catalpa) (Figure 12e). Iron is a naturally occurring element and an essential trace element for trees. The higher concentrations of Fe were in trees that contained PCE and TCE. The trees with the highest iron concentration were also the trees with the highest TCE (T64) and the highest PCE (T32). Iron has been shown to be taken up by trees at sites characterized by iron-rich leachate (Snow and others 2008).

Copper was detected above the average MDL of 0.41 ppm in all but three samples (Table 3). The copper concentrations in the trees cored varied widely and ranged from 0.40 to 7.30 ppm; the mean was 3.85 ppm. The trees with higher than mean concentrations were T25(Magnolia), T31 (Oak, Laurel), T17 (Ginko), T6 (Catalpa) (Figure 12f). Copper is a naturally occurring element and an essential trace element for trees but copper also is used in many industrial processes including the CPI. The higher concentrations of copper were in trees that contained PCE and TCE.

Zinc was detected above the average MDL of 0.43 ppm in all samples (Table 3). The zinc concentrations in the trees cored varied widely and ranged from 1.80 to 9.30 ppm; the mean was 5.13 ppm. The trees with higher than mean concentrations were T59 (Oak, Laurel), T29 (Oak, Live), T15 (Oak, water), T23(Maple, red), T25(Magnolia), T31 (Oak, Laurel), T17 (Ginko) (Figure 12g). Zinc is a naturally occurring element and an essential trace element for trees but also is used in industrial processes, such as in the CPI to manufacture zinc plates. The higher concentrations of zinc were in trees that contained PCE and TCE. Zinc has been shown to be taken up by trees with translocation to shoots (Pulford and others 2001).

Sulfur was detected above the average MDL of 7.66 ppm in all samples (Table 3). The sulfur concentrations in the trees cored varied widely and ranged from 94.00 to 264.00 ppm; the mean was 149.09 ppm. The trees with higher than mean concentrations were T32 (Oak, Live), T59 (Oak, Laurel), T29 (Oak, Live), T17 (Ginko), T3(Sycamore) (Figure 12h). Sulfur is a naturally occurring element and an essential trace element for trees but also is used in industrial processes, such as in the manufacture of inks. The higher concentrations of sulfur were in trees that contained PCE and TCE. The sulfur contect of wood has been examined by Fairchild and others (2009). Manganese was detected above the average MDL of 0.94 ppm in all samples (Table 3). The manganese concentrations in the trees cored varied widely and ranged from to 3.9 to 80 ppm; the mean was 16.8 ppm. Silica was detected above the average MDL of 12.8 ppm in all samples (Table 3). The silica concentrations in the trees cored varied widely and ranged from 27.3 to 236 ppm; the mean was 62.4 ppm. (Figure 12i). Aluminum was detected above the average MDL of 18.9 ppm in only one sample (Table 3). Aluminum was detected at 51.9 ppm in T29. Aluminum was used in the CPI for plates. Nickel was detected above the average MDL of 0.46 ppm in all samples (Table 3). The nickel concentrations in the trees cored ranged from 0.89 to 1.8 ppm; the mean was 1.33 ppm. (Figure 12j).

Concentrations of metals were measured for trees sampled in Columbia, SC, a similar urban capital city in the southeastern United States (data not shown). Only one tree-core sample (out of eight collected) had strontium, and at a concentration of 5.66 ppm, which is half of the mean of the strontium concentration at the CCP Site. No trees cored in SC had rubidium. All trees had chloride, but the highest was 66 ppm, half what the highest core from the CCP Site had. The average chromium in trees from Columbia was similar to the average for the CCP Site. The concentration of sulfur in tree cores at the

CCP Site was higher than for Columbia. The concentrations of iron and silica in tree cores at the CCP Site was higher than for Columbia. Conversely, the concentration of zinc and aluminum in trees was higher in Columbia than at the CCP Site.

Groundwater Sampling and Analysis

Groundwater samples were collected during April–May 2009 by the USGS to confirm or refute the contaminant distribution indicated by the tree-core survey in August 2008 and to document any changes in concentrations over time since the most previous groundwater sample results from previous reports. Results for redox sensitive field parameters (dissolved oxygen, sulfide, sulfate, nitrate) and turbidity, specific conductance, and pH are shown in Table 4. The groundwater samples collected as part of the May 2010 sampling event conducted by the USEPA will be described in the section on SF_6 concentrations. In general, the groundwater in the shallow part of the shallow aquifer sampled in April–May 2009 was oxic (DO ranged from 4 to 6.4 milligrams per liter (mg/L) from the Hach kit, or 2.6 to 6.6 mg/L from the YSI meter), contained between 4 and 19 mg/L sulfate, 1.5 and 7.1 mg/L nitrate, 0 and 5 mg/L ferrous iron; 0.1 and 1.3 NTUs of turbidity; 70 and 322 µS/cm conductivity; and pH between 5 and 7.3 (Table 4). In general, the groundwater in the intermediate aquifer is oxic (DO ranged from 2.2 to 6.6 mg/L from the Hach kit, or 1.8 to 6.9 mg/L from the YSI meter), contains between 1 and 6 mg/L sulfate, 0.7 and 6.6 mg/L nitrate, 0 and 5 mg/L ferrous iron, 0.6 and 1.7 NTUs of turbidity, 60 and 212 µS/cm conductivity, and pH between 5.2 and 6.1 (Table 4).

Table 4. Field parameters measured in groundwater during sampling in April–May 2009.

Results for organic contaminants detected in monitoring wells at the CCP Site are shown in Table 5 and the distribution shown in Figure 13. Perchloroethylene was detected above the method reporting level (MRL) of 0.04 µg/L in all wells sampled with the highest concentrations in MW-1S (5.2 µg/L), MW-2S (25 µg/L), MW-4S (85 µg/L) MW-5I (7.7 µg/L), MW-8S (18 µg/L) and -12S (63 µg/L). Trichloroethylene was detected above the MRL of 0.02 µg/L in eight wells and the highest concentration of TCE at 9.62 µg/L was detected in well MW-4S that also had the highest PCE concentration. The transformation byproducts of PCE and TCE of *cis*-1,2-DCE and *trans*-1,2-DCE were detected in one and three wells, respectively, with the highest concentrations in well MW-4S. Also, the compound 1,1-DCE was detected in four wells with the highest concentration of 1.68 µg/L in MW-8S, above the MRL of 0.02 µg/L. The solvent diisopropyl ether (DIPE) was detected at 0.22 µg/L, above the MRL of 0.06 µg/L, in two wells, MW-4S and -12S. The detection above the MRLs of CFC-113 and CFC-11occurred in MWs-4S, -9S, and -12S, and MWs-2S, -4S, -8S, and 9S, respectively. Elevated levels of these CFCs in groundwater is common in urban areas (Plummer and Friedman 1999) as CFCs were used during many industrial processes. Chloroform was detected at concentrations above the MRL of 0.04 µg/L, and will be discussed in a following section. Moreover, PCE concentrations above the MRL were measured in wells screened to the intermediate part of the shallow aquifer; MW-1I, -5I (at 5.5 µg/L, just above the MCL), -7I, -8I, and -12I (Table 5). Concentrations of TCE above the MRL were measured in intermediate wells MW-5I and -12I (Table 5). These detections in the deeper part of the shallow aquifer imply that (1) the contaminant release was not recent, as the depth of the screened interval implies a lengthy travel time for groundwater and contaminants, and (2) that the upper part of the shallow aquifer known to be contaminated since 1993 is not the only part of the aquifer affected by the release.

Table 5. Volatile organic compounds in groundwater sampled in April–May 2009.

Figure 13. Locations of (a) PCE and (b) TCE in groundwater, data from USGS sampling April–May 2009, with former locations and dates occupied by a major commercial printing industry. PCE data for 9W are from the MWWSSB.

Good agreement between August 2008 tree-core data for VOCs with VOC data from groundwater collected in April–May 2009 (Figure 14). In general, PCE was detected in trees growing near or upgradient of monitoring wells that contained PCE. PCE also was detected in areas where no monitoring wells were located, but were within the areas designated as boundaries for the CCP Site. PCE was detected in four trees to the west of Washington and Dexter Avenues; in the block of the RSA Tower Energy Plant, near the City waterworks, and riparian zones of Cypress Creek and the Alabama River. The highest concentration of PCE in the vial-headspace was for T32 near the RSA Energy Plant, where the depth to water table is about 35 ft bls. In general, TCE was detected in trees growing near or upgradient of monitoring wells that contained TCE. TCE was detected in multiple trees growing near or upgradient of wells that did not contain TCE in August 2007 (i.e., MW-9S, -1S, and -5S). TCE also was detected in areas where no monitoring wells were located, but were within the areas designated as the boundaries of the CCP Site. TCE was detected in four trees along the 200 block of Washington Avenue; MW-9S had TCE at 0.03 μg/L (estimated). TCE also was detected in trees along Dexter Avenue; Monroe Street, McDonough Street, Lawrence Street, and Hult Street, and downgradient in riparian areas of Cypress Creek and the Alabama River. As stated previously, the detection of TCE in the headspace of vials that contained tree cores from trees that grow upgradient of the location of previously identified TCE groundwater contamination at the RSA Energy Plant provides the first evidence of the existence of an upgradient, near-surface source of TCE located along Washington Avenue .

Figure 14. Locations of (a) PCE and (b) TCE and (c) chloride in tree-core vial headspace, ppbv, data from USGS sampling August 2008, with former locations and dates occupied by a major commercial printing industry.

Inorganics also were detected in groundwater (Table 6). Chromium was detected at much lower concentrations than reported in groundwater during sampling in July 2007 (Hall 2007). A possibility of the lower chromium concentrations in April–May 2009 is the lower turbidity relative to the turbidity reported during sampling in July 2007 (Figure 15). The groundwater sampled during April–May 2009 by the USGS was done using low-flow methods as described in the methods section.

Table 6. Groundwater inorganic data from April–May 2009 sampling.

Figure 15. Comparison of the effect on (a) chromium concentrations in groundwater of (b) groundwater sample turbidity between sampled collected in April–May 2009 by the USGS and samples collected in July 2007 (Hall 2007). The higher chromium levels in July 2007 appear to be related to the higher turbidity levels as a result of non-low flow sampling techniques.

Chloroform Concentrations

Concentrations of chloroform were low in most wells sampled (0.6 to 0.71 µg/L) and were representative of ambient chloroform concentrations of groundwater measured in the United States (Zogorski and others 2006). However, much higher concentrations of chloroform were detected in groundwater from a cluster of shallow wells—MW-1S at 37.3 µg/L and in nearby shallow wells MW-4S, -2S, and -9S at concentrations of 1.96, 2.65, and 2.98 µg/L, respectively (Figure 16). Chloroform in groundwater at concentrations greater than ambient local and regional levels is indicative of recharge by treated municipal water in addition to water supplied by ambient precipitation (Ivahnenko and Barbash 2004). Additional evidence of localized groundwater recharge by municipal water in the vicinity of MW-1S is provided by this well having the highest pH measured in all wells (7.3) during April–May 2009. These data indicate that groundwater sampled from the shallow well-pair at MW-1S, and to a lesser extent MW-4S, -2S, and -9S, contain a significant component of treated municipal water.

Figure 16. CCP Site wells with chloroform plume, April 2009, with former locations and dates occupied by a major commercial printing industry.

The presence of a geochemical fingerprint (chloroform) in shallow groundwater in a cluster of wells MW-1S, -4S, -2S, and -9S that indicates treated municipal water at depths at least 30 ft bls, and absence of chloroform in other shallow wells in the CCP Site, raises the question of "How did treated municipal water recharge shallow groundwater, and in only this area?" The simplest explanation is the treated municipal water has reached shallow groundwater through leaks, flat spots, joints, or decreased gradients in the pipes of the City's sanitary sewer system (Figure 17). Any leaks present in the sanitary sewer system were probably exacerbated during times of intense rainfall such that stormwater runoff may have intermittently entered the sanitary sewer system. A recent study reported that sewer systems can be a conduit for the migration of subsurface contamination (Vroblesky and others 2009).

Figure 17. Locations of monitoring wells, approximate location of the sanitary sewer system, and slopes between outfalls with presumed flow directions, and chloroform data.

The cluster of shallow wells characterized by high chloroform concentrations in April–May 2009 also are characterized by PCE and TCE contamination since sampling in 2000. This co-occurrence of municipal water, PCE-, and TCE-contamination provides evidence on the contaminant pathway of how PCE and TCE detected in groundwater beneath the downgradient RSA Energy Plant entered the shallow aquifer from an upgradient source area. The proposed pathway revealed by this co-occurrence is from industrial trade-wastewater that contained PCE and TCE that entered the sanitary sewer system, leaked into the subsurface, and then migrated through the unsaturated zone to groundwater. Specifically, industrial trade-wastewater from the CPI located along Washinton and Dexter Avenues between 1940 and 1997 was disposed of in the sewers, drains, and sumps and mixed over time with regular municipally derived wastewater (U.S. Environmnetal Protection Agency 2009 104(e) Information Requests). The mixed wastewater then flowed downgradient and entered the subsurface through leaks, and the reached the water table beneath the RSA Energy Plant after the relatively slow processes of infiltration through the thick unsaturated zone.

The proposed contamination pathway between the former location of a major CPI, the presence of drains at the location, the sanitary sewer system, and groundwater also helps explain why no near-surface soil contamination by PCE or TCE was uncovered during initial site assessments that occurred near the RSA Energy Plant since 1993, and why the acute exposure occurred only when the excavation reached depths near the water table, as PCE and TCE

(1) Were not released at the location of the RSA Enegy Plant, even though groundwater beneath was found to be contaminated by PCE and TCE in 1993

(2) The PCE and TCE were released to the sewer system upgradient along Washington Avenue and then migrated after leakage between Washington Avenue and Dexter Avenue to the water table, which explains why little near-surface soil contamination was evident during previous investigations.

Determination of the Probable Release History

Sulfur Hexafluoride and Chlorofluorocarbon Concentrations

To confirm or refute the potential contamination pathway of disposal into the sanitary sewer and leakage into groundwater as raised by the results of the groundwater sampling during April–May 2009, concentrations of SF_6 and CFCs in wells sampled during field activites conducted by the USEPA in May 2010 were analyzed by the USGS. Groundwater in the shallow wells that had the highest chloroform concentrations in April–May 2009 were characterized by the youngest groundwater age as determined from the SF_6 concentrations, and confirms the presence of a localized source of water that contains water that is between 2.4 y (MW-2S) and 22.4 y old (MW-9S) (Figure 18). The presence of such young recharge in shallow groundwater in this area confirms the existence of an ongoing hydraulic connection between land surface and groundwater, as would be required to support the contaminant pathway of leakage of municipal water from the sanitary sewer system.

Figure 18. Monitoring wells a(shallow) and b(intermediate) wells that contained SF_6, May 2010.

Groundwater sampled in May 2010 was characterized by detectable concentrations of CFCs (Figure 19a,b). The detection of CFCs in groundwater indicate a local contaminant source of CFCs as previously described but wells with ambient atmospheric concentrations were used to determine the recharge date of groundwater. The CFC-contaminanted wells were the same four wells that contained elevated concentrations of chloroform, or wells MW-1S, -4S, -2S, -9S, and, additionally, MW-10S. The other wells had lower CFC concentrations that did not reflect local contamination but rather the interaction of ambient atmospheric levels of CFCs with groundwater.

Figure 19. Monitoring wels a(shallow) and b(intermediate) wells with CFC concentrations, May 2010.

The groundwater with the oldest recharge date was from the early 1940s and collected from the most downgradient well sampled, MW-12S. An upgradient well (MW-7S) had a CFC-based recharge date of 1948, and farther upgradient, well MW-1I had the youngest CFC-based recharge date of 1960 (Figure 20a,b).

Figure 20. CFC-based recharge age dates, May 2010.

The age difference between groundwater from wells MW-1I (1960) and downgradient well MW-12I (1940) when used with the distance between them (1,900 ft), enables a groundwater-flow rate of about 95 ft/y to be estimated. This is in good agreement with the 100 ft/y determined from slug tests in 2002 during the RI (Black & Veatch 2002).

The rate of groundwater flow, when combined with the initial detections of PCE and TCE in monitoring wells at the CCP Site over time, was used to determine the approximate time of contaminant release. For example, PCE was first detected in well 9W in 1991 (Figure 21). The distance between well 9W and the former location of a major CPI along Washington Avenue between 1940 and 1997 is about 3,200 ft. If the ambient, unpumped groundwater flow rate is about 100 ft/y from slug tests (Black & Veatch 2002) and CFC-age dates (this report), then a potential release history from that source area to arrival in well 9W would be no later than the mid-1970s. This data, along with the CFC-based recharge dates, constrains the probable release time to between the early 1940s and late 1970.

Figure 21. Well 9W PCE and TCE trends over time, 1991 to 2009.

The trends of PCE and TCE in well 9W reveal not just the past release history but also indicate potential future contaminant trends. For example, since 1991 PCE is always higher in 9W than TCE when are both present. Well 9E (located just to the east of 9W) was turned off in 1997, which may explain why prior increases in PCE in well 9W stopped as pumped-gradient conditions returned to ambient-unpumped gradient conditions and groundwater flow rates decreased. In well 9W, TCE was detected in 2000 and increased to a peak in 2003, then decreased. Meanwhile, PCE was stable or only slightly increasing. One reason for these differences in contaminant concentrations and arrival times is not necessarily due to different release times but because TCE is five times more soluble in water than PCE (1,000 mg/L compared to 275 mg/L). As a result, PCE and TCE released at the same location at the same time would produce a scenario where the plume of TCE would be detected initially at a well and then followed by the detection of the less soluble PCE.

As PCE in MW-2S has decreased since 1993, a roughly equal increase of PCE has been observed in downgradient and nonpuming well 9W (Figure 22a). The distance between these two wells is roughly 2,100 ft, and the time difference between peaks is about 16 y. Peak-concentration (PCE at 120 ug/L) contaminant transport rate would be, therefore, about 131 ft/y. PCE in MW-3S and 9W were similar up until 1995, when PCE in 9W decreased and PCE in well MW-3S slightly increased. Since 2003, PCE has increased in both wells, although to a greater extent in 9W (Figure 22b). In well MW-4S, the concentration of PCE is ten times higher than TCE, and has been consistently high since 1999 (Figure 22c). A probable explanation is that there is an adjacent residual source of PCE close by, such as near the RSA Tower Energy Plant. PCE in upgradient well MW-8S decreased between 2000 and 2009, and PCE increased in downgradient 9W. Essentially, this trend records the movement of the PCE plume downgradient from Washington Avenue (Figure 22d). Much like for contaminant trends in MW-2S and MW-8S, as the concentration of PCE in well MW-12S decreases, the PCE in 9W increases (Figure 22e)—this trend records the movement of PCE from MW-2S to MW-8S to MW-12S downgradient toward, ultimately, well 9W.

Figure 22. PCE and TCE in site MWs over time relative to 9W (a-g).

Dendrochemistry

The results for the tree-core survey conducted in 2008 were used to guide the collection of additional and longer tree cores during January 2009 (Figure 23). In some trees, such as T47 and T23, it was possible to discern the time of arrival of peaks, or pulses, of high metal concentrations, to between 1940 and 1970, such as for chloride and chromium, in datable annual growth rings (Figure 24). A similar approach was proven to be successful in the determination of the release history at a site characterized by chlorinated-solvent-contaminated groundwater (Yanosky and others 2001).

Figure 23. City map with trees used for dendrochemistry shown with former locations and dates occupied by a major commercial printing industry.

Figure 24. Dendrochronological data for chloride and chromium for T47 and T23.

The Commercial Printing Industry and Chlorinated-Solvent-Contaminated Groundwater at the Capital City Plume Site

The CPI is one of the largest industries in the United States (Printers' National Environmental Assistance Center, www.pneac.org). The CPI consumes large volumes of organic and inorganic chemicals used in chemical reactions associated with various printing operations from letterpress to lithography to offset printing of either sheet-fed or continuous-fed presses that print in one to eight colors (Table 7) for production of the final printed matter. Lithography is the most common of the major printing processes (USEPA 2007). Up to 99% of the chemicals used are released to the air (SIC 1995, USEPA National Emissions Inventory, CPI ranks 5th in VOC emissions, one ahead of automobile industry), with the balance released to water or land or become part of the final printed product. These printing operations involve the use of large volumes of organics and metals.

Table 7. List of historic dates of the Commercial Printing Industry.

Organics

One of the most commonly used solvents in the printing industry is blanket wash (Sinha and Achenie 2001). Blanket wash is used for lithographic printing processes based on the repulsion of oil and water where the water-based part is called a fountain solution. The fountain solution cleans the background area of a plate not to be printed and is comprised of water-soluble organics such as alcohols. In off-set applications of lithography (Figure 25), a plate that contains the image to be printed never actually touches the paper but instead comes into contact with a rubber blanket to which the plate is applied. Plates can be made of zinc, aluminum, or lead, and often done on site using a linotype machine. According to a survey of three blanket wash producers in 1992 and estimated to represent 70% of the CPI, blanket wash (or roller wash) can consist of 1,1,1-TCA, toluene, TCE, and PCE (*www.pneac.org*). Blanket wash is used to clean residues such as old ink, paper fibers, and paper coatings from rubber rollers, called blankets, used for lithographic printing presses. The blanket wash is applied by either automatic or manual methods, having been primarily manual throughout the history of the CPI. The manual method involved wiping down the blanket cylinder with cloth rags dampened with blanket wash, called “rag and bucket” (Sinha and Achenie 2001). Blanket wash was typically stored on site in 55 gal drums. Blankets are typically cleaned before each press run or at the end of each shift to ensure excellent print quality (NT May 1999). Prior to the development in the 1970s of industries to handle the soiled rags, rag management was the responsibility of each printpress room. The amount of blanket wash solution used per pressroom is unknown, but has been estimated at 160 gallons per year (gal/y.; United States Environmental Protection Agency 1997a). A list of the chemicals commonly used in the printing industry is provided in Table 8 (USEPA 1997b). Included on the list are the “F”-listed wastes such as spent halogenated solvents, such as PCE, TCE, 1,1,1-trichloroethane (1,1,1-TCA), CFC-113, methylene chloride, methyl ethyl ketones, used for degreasing and cleaning, and non-halogenated solvents such as toluene.

Figure 25. Offset printing press.

Table 8. List of F-listed wastes that include those used in the Commercial Printing Industry (USEPA 1997b).

Metals

Metals are used to meet a variety of needs in the CPI. Although some organic-based pigments have been used in inks, inorganic pigments comprised of heavy metals were more often used. Pigments include the colors of white (titanium), yellow (bismuth, chromium, and cadmium; "school-bus" yellow), orange (molybdenum), iron (blue), green (chromium or copper), black (rubidium, strontium), red (barium and zinc) (Buxbaum 1998). Most pigments are metal salts or oxides. Heavy metals such as cobalt and manganses also are used as driers. Other toxic chemicals used by the CPI are listed in USEPA (1997b) and include barium, chromium, and silver. Inorganics also are used as acids (sulfuric acid), and plate developers (silver; USEPA 1997b, Appendix F) or silver as a photographic fixer. Moreover, fountain solutions also have contained metals such as chromium, magnesium, phosphate, and silica. Mixtures of organics and metals also are used in the CPI. For example, solvents are often mixed with inks where the solvent acts as the vehicle for the pigments and dyes, much like water is used as the vehicle for pigments with watercooler painting.

Commercial Printing Industry in Montgomery

The CPI has been a large part of the history of Montgomery. Mulitple locations of a major newspaper have existed since 1828 in Montgomery. Mention various location changes over time (Table 9).

Table 9. Timeline of Commercial Printing Industry events at Montgomery, Alabama.

Responses to USEPA Section 104(e) Information Requests for the CCP Site indicate that chemicals used during the CPI operations at 200 Washington Avenue resulted in the generation of trade wastewater in the pre-press area that was disposed of down floor drains or sinks that were connected to the sanitary sewer system by a sump pump, or were laundered on site with discharge to a sump and then by pipe to a road surface and into the stormwater system, a widespread practice prior to the late 1970s when soiled rags were laundered by off-site vendors (USEPA 104(e) IR 2009). Moreover, soiled rags were laundered on site or disposed of down drains–rags were found in the sewer and stormwater pipes in downtown Montgomery by MWWSSB employees (Buddy Morgan, MWWSSB, personal communication, 11/16/2009). Smaller printing operations were conducted at 116 McDonough Street. There, more than one color products were made. Blanket washes were used on rags. Spent fountain solutions were drained down a sink. Plate developers also were disposed of down the sink.

Summary

The data collected between 2008 and 2010 by the USEPA and USGS for additional assessments of the potential source area, contamination pathway, and the probable release history at the CCP Site support the following determinations (the numbers refer to specifc locations or processes depicted on Figure 26:

<u>Potential Source Area</u>:

1. The detection of TCE in trees growing along Washington Avenue in August 2008 indicates a near-surface residual source of TCE in that immediate area. The detection in April–May 2009 of TCE in groundwater from adjacent MW-9S supports this TCE-source area determination. Moreover, the TCE concentration detected in T64 growing along Washinton Avenue was the highest TCE tree-core headspace concentration measured by the authors.
2. The presence of high organic vapor concentrations from sediments cored from the 50-ft thick unsaturated zone during vibracore drilling and installation of MW-9S and MW-10S indicated a near-surface residual source of VOC contamination in the vicinity of Washington and Dexter Avenues, respectively, as early as 2000. Moreover, additional evidence that this is a potential source area was provided by the detection of PCE in air samplers placed in the basement of a building on Washington Avenue that was a former location of a major CPI (Scott Miller, USEPA, personal communication, 12/14/2010).
3. The detection of PCE in trees growing at the junction of Perry Street with Washington Avenue in August 2008 indicates a near-surface residual source of

PCE in that immediate area. PCE has been detected in MW-4S downgradient of these trees since 2000.

Contamination Pathway:

4. TCE was detected in trees growing along McDonough Street in August 2008. The trees are growing in general alignment with the sanitary sewer system beneath McDonough Street that conveys wastewater from upgradient sources that include the TCE-residual source area located along Washington Avenue described above. These data indicate that CPI-trade wastewater that contained TCE entered the sanitay sewer system along Washington Avenue, leaked from the sanitary sewer system from beneath McDonough Street and Dexter Avenue, and recharged the water table along Monroe Street—this pathway led to the TCE- and PCE-plumes beneath the RSA Energy Plant first detected in 1993.
5. PCE was detected in trees growing along Perry Street in August 2008. The trees are growing in general alignment with the sanitary sewer and stormwater systems beneath Washington Avenue and Perry Street. These data indicate that CPI-trade wastewater that contained PCE entered and leaked from the sanitary sewer system and(or) was released to the stormwater sytem and recharged the water table along Monroe Street.
6. The absence of detectable organic vapor concentrations from sediments cored from the 30-ft thick unsaturated zone **above** the water table during vibracore drilling and installation of well pairs MW-1S,I and MW-4S,I in 2000 and presence of high organic vapor concentrations **at** or **below** the water table

indicate that PCE- and TCE-groundwater contamination detected in thoses wells did **not** occur by downward vertical migration through the unsaturated zone but, rather, the groundwater contamination resulted from lateral groundwater flow from PCE- and TCE-contaminated groundwater located upgradient along Washington Avenue.

7. The detection of chloroform at concentrations indicative of treated municipal water in groundwater from MW-1S confirms the following contaminant pathway: PCE- and TCE-contaminated CPI-trade wastewater were released to sinks, sumps, and floor drains in buildings located along Washinton Avenue—this wastewater entered the sanitary sewer system—this wastewater entered the subsurface through leaks and(or)joints—this water was then transported through the usaturated zone to near MW-1S. Moreover, this contamination pathway is supported by independent lines of evidence from MW-1S, such as the presence of young water as determined by detection of high SF_6 concentrations and the presence of high concentrations of CFC-113.

<u>Probable Release History</u>:

8. The release of PCE- and TCE-contaminated CPI-trade wastewater into the sanitary sewer system most likely occurred between the 1940s and 1970s as supported by the SF_6- and CFC-calculated groundwater-age dates. This timeframe also was when the CPI switched to these solvents.
9. Dendrochemical results of tree-rings from trees growing along McDonough Street downgradient fromWashington Avenue indicate the peak arrival of

chlorides (derived from solvents) and chromium (from inks or wash water) during the 1960s.

Figure 26. Depiction of the potential source area, contaminant pathway, and probable release history of PCE- and TCE-contaminated groundwater at the Capital City Plume (CCP) Site, Montgomery, Alabama.

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Table 1. Timeline of previous investigations and events important to the additional assessments of the Capital City Plume Site, Montgomery, Alabama, 1819–2010.

[[1]ATSDR accessed 10/1/2008; [2]Black & Veatch 2002; [3]Malcolm Pirnie, Inc., 2003; [4]Envrionmental Materials Consultants, Inc., 2003; [5]JM Hall SEA, 2007; [6]this report; [7]Scott and others 1987; [8]Knowles and others 1963.]

Date[1]	Event
1819	City of Montgomery incorporated.
1860s	Stormwater sewer system built in Montgomery[1].
1885	Montgomery municipal water supplied by well fields, including the Northeast well field[1,8].
1941	The West well field developed.
1950	The Water Works and Sanitary Sewer Board took over Montgomery wellfields[8].
1962	Public supply wells 9W and 9E drilled in the shallow aquifer, screened from 69 to 79 ft bls, and 64 to 74 ft bls, respectively[2,7].
1965	C.T. Perry Water Purification Plant built on Tallapoosa River to treat surface water for municipal distribution. Water is disinfected by chlorination. Wells still used.
1970	Montgomery sewage, previously discharged to the Alabama River, now sent to Econchate Waste water treatment plant.
1980	Superfund legislation passed.
1991–92	PCE at 7.1 µg/L detected in public supply well 9W in April 1991 and PCE at 21 µg/L in wells 9W and 9E in May 1992, both in the shallow aquifer; MWWSSB[2].
1992	Well 9W taken out of service due to PCE.
September 1993	Workers overcome at about 25 ft bls by vapors during soil excavation for RSA Energy Plant[2]. Contaminated soil excavated and removed[2].
October 1993	ADEM Phase I Investigation[2].
November 1993	ADEM Phase II Investigation[2].
February 1995	

	ADEM Preliminary Assessment (PA) confirms detection of PCE in shallow groundwater near the RSA Energy Plant[2].
1996	The RSA Tower is built near RSA Energy Plant. ADEM recommends that the CCP Site be considered for the Superfund list.
1997	Well 9E shut down[2].
2000	USEPA begins a Remedial Investigation (RI)[2]. USEPA proposes to list the CCP Site on the NPL.
2001	USEPA collects additional soil samples at the RSA Energy Plant.
2002	USEPA sampling detects PCE in Cypress Creek.
2003	City of Montgomery begins Feasibility Study[3]. The Montgomery County Commission initiates an Environmental Site Assessment of former Montgomery Advertiser property on Washington Street[4].
2007	City of Montgomery initiates a groundwater samping event that indicates PCE remains in wells[5].
August 2008	The USEPA and USGS conduct an assessment of the potential source of groundwater ontamination[6].
January 2009	The USEPA and USGS conduct an assessment of the probable release history of groundwater contamination[6].
April–May 2009	The USEPA and USGS conduct an assessment of the groundwater contamination[6].
May 2010	The USEPA and USGS conduct an additional assessment of the groundwater contamination[6].
December 2010	This report[6].

[1] Table footnote

Table 2. Concentrations of perchloroethylene (PCE) and other volatile organic compounds in tree-core samples collected from downtown and around Montgomery, Alabama, during August 2008.

[All concentrations in parts per billion by volume of vial headspace; nm, not measured; the method reporting level (MRL) for PCE, TCE, *cis*-1,2-DCE, and benzene was 2, 10, 15, and 10 parts per billion by volume (ppbv), respectively; core identifier refers to multiple cores collected from a particular tree]

Tree identifier	Tree description	Core indentifier	Diameter at Breast height (inches)	Analysis date	Core collected date	PCE	TCE	cis-DCE	Benzene	Heating seconds	Comments
T1	Cottonwood	A	12	8/19/2008	8/18/2008	nm	nm	nm	nm	30	Microwaved for 30 sec.
T5	Cottonwod	B	31	8/19/2008	8/18/2008	0	<20	0	0	30	Microwaved for 30 sec.
T5		C		8/19/2008	8/18/2008	0	<20	0	0	30	Microwaved for 30 sec.
T1		B		8/19/2008	8/18/2008	0	<20	0	0	30	Microwaved for 30 sec.
T1		C		8/19/2008	8/18/2008	0	<20	0	0	30	Microwaved for 30 sec.
T2	Sycamore	A	24	8/19/2008	8/18/2008	553	<20	0	0		Microwaved for 30 sec.
T2		C		8/19/2008	8/18/2008	167	31	0	0	30	Microwaved for 30 sec. Injected 250 uL.
T4	Sycamore	B	14	8/19/2008	8/18/2008	0	<20	0	0	30	Microwaved for 30 sec. Injected 250 uL.
T4		A		8/19/2008	8/18/2008	0	<20	0	0	30	Microwaved for 30 sec. Injected 250 uL.
T3	Sycamore	A	23	8/19/2008	8/18/2008	0	<20	0	0	30	Microwaved for 30 sec. Injected 250 uL.
T3		B		8/19/2008	8/18/2008	0	<20	0	0		Microwaved for 30 sec. Injected 250 uL.
T3		C		8/19/2008	8/18/2008	0	<20	0	0	30	Microwaved for 30 sec. Injected 250 uL.
T3		D		8/19/2008	8/18/2008	0	24	0	0		Microwaved for 30 sec. Injected 250 uL.
T2		A		8/19/2008	8/18/2008	0	0	0	0	30	
T7	Red maple	A	12	8/19/2008	8/19/2008	0	0	0	0	30	
T7		AR1		8/19/2008	8/19/2008	0	68.23	0	0	30	Rerun of T7. Injected 100 uL.
T7		AR2		8/19/2008	8/19/2008	0	73.98	0	0	30	Composite sample, injected 250 uL, rerun of T7.

T8	Sycamore	A	12	8/19/2008	8/19/2008	0	243	0	0	30	Composite sample. Injected 100 uL.
T9	Cottonwood	A	31	8/19/2008	8/19/2008	0	0	0	0	15	Composite sample. Injected 100 uL.

Table 2. Concentrations of perchloroethylene (PCE) and other volatile organic compounds in tree-core samples collected from downtown and around Montgomery, Alabama, during August 2008--Continued.

[All concentrations in parts per billion by volume of vial headspace; nm, not measured; the method reporting level (MRL) for PCE, TCE, *cis*-1,2-DCE, and benzene was 2, 10, 15, and 10 parts per billion by volume (ppbv), respectively; core identifier refers to multiple cores collected from a particular tree]

Tree identifier	Tree description	Core indentifier	Diameter at Breast height (inches)	Analysis date	Core collected date	PCE ppbv	TCE ppbv	Cis-DCE ppbv	Benzene ppbv	Heating seconds	Comments
T11	Elm	flower	nm	8/19/2008	8/19/2008	0	0	0	0	15	Flower, injected 100 uL.
T11	Elm		17	8/19/2008	8/19/2008	0	0	0	0	15	Composite sample, injected 100 uL.
T10	China berry	SX2	32	8/19/2008	8/19/2008	0	0	0	0	15	Composite sample, injected 100 uL.
T10		SX2rerun		8/19/2008	8/19/2008	0	0	0	0	20	Composite sample, injected 100 uL.
T10		B		8/19/2008	8/19/2008	0	0	0	0	15	Composite sample, injected 100 uL.
T12	Catalpa	A	30	8/19/2008	8/19/2008	0	0	0	0	15	Single core, injected 100 uL.
T12		B1		8/19/2008	8/19/2008	14	168	0	0	30	Single core, injected 250 uL.
T12		B2		8/19/2008	8/19/2008	0	0	0	0	30	Reinjection of T12B1 with clean 100 uL syringe.
T12		B3		8/19/2008	8/19/2008	0	0	0	0		Reinjection of T12B1, with clean 250 uL syringe.
T12		B4		8/19/2008	8/19/2008	26	140	0		20	Reinjection of T12B1, with 250 uL syringe.
T12		A2		8/19/2008	8/19/2008	0	0	0		20	Reinjection of T12A; injected 250 uL.
T Catalpa		Cat1	nm	8/19/2008	8/19/2008	0	2877	0		20	250 mL syringe blank injected 200 mL
T13	Pecan		nm	8/19/2008	8/19/2008	0	0	0		15	Composite sample,

											injected 200 uL
T14	Willow		nm	8/19/2008	8/19/2008	0	61	---	0	15	Composite sample, injected 200 uL
T15	Oak		44	8/19/2008	8/19/2008	0	0	0		15	Composite sample, injected 200 uL
T16	Sycamore		14	8/19/2008	8/19/2008	0	0	0	0	15	Composite sample, injected 200 uL
T17	Ginko		13	8/19/2008	8/19/2008	0	254	0	0	15	Composite sample, injected 200 uL
T18	Oak		nm	8/19/2008	8/19/2008	0	302	0	0	15	Composite sample, injected 200 uL
T19A	Oak	A	21	8/19/2008	8/19/2008	0	104.8	0	0	15	Composite sample, injected 200 uL
T19B		B	21	8/19/2008	8/19/2008	0	0	0			
T2		AAA	24	8/19/2008	8/19/2008	39.75	0	0			
T20	Ginko	A	19	8/19/2008	8/19/2008	0	0				0
T21	Oak	A	17	8/19/2008	8/19/2008	0	38		0	15	Injected 200 uL.
T21		B		8/19/2008	8/19/2008	0	84				0
T22	Sycamore	A	17	8/19/2008	8/19/2008	0	0				0
T22		B		8/19/2008	8/19/2008	0	32				0
T23	Maple	A	7	8/19/2008	8/19/2008	0	0				0
T23		B	7	8/19/2008	8/19/2008	0	0				0
T20		B		8/20/2008	8/19/2008	0	0				0
T29	Oak	A	8	8/20/2008	8/19/2008		144				
T29		B	8	8/20/2008	8/19/2008	0	301				0
T Catalpa		CATB	nm	8/20/2008	8/19/2008	0	<100				0

T Catalpa		CATC	nm	8/20/2008	8/19/2008	0	<100	0
T12B		BD	29	8/20/2008	8/19/2008	0	<100	0
T24	Oak, lurel	A	32	8/20/2008	8/19/2008	0	<100	0
T24		B		8/20/2008	8/19/2008	0	<100	0

Table 2. Concentrations of perchloroethylene (PCE) and other volatile organic compounds in tree-core samples collected from downtown and around Montgomery, Alabama, during August 2008--Continued.

[All concentrations in parts per billion by volume of vial headspace; nm, not measured; the method reporting level (MRL) for PCE, TCE, *cis*-1,2-DCE, and benzene was 2, 10, 15, and 10 parts per billion by volume (ppbv), respectively; core identifier refers to multiple cores collected from a particular tree]

Tree indentifier	Tree description	Core indentifier	Diameter at Breast height (inches)	Analysis date	Core collected date	PCE ppbv	TCE ppbv	Cis-DCE ppbv	Benzene ppbv	Heating seconds	Comments
T25	Magnolia	A	13	8/20/2008	8/19/2008	0	<100	0	0	8	Short heat because it was collected yesterday, Injected 200 uL.
T25		B	13	8/20/2008	8/19/2008	0	<100	0	0	8	Short heat because it was collected yesterday, Injected 200 uL.
T26	Ginko	A	9.75	8/20/2008	8/19/2008	0	<100	0	0	8	Short heat because it was collected yesterday, Injected 200 uL.
T26		B		8/20/2008	8/19/2008	0	<100	0	0	8	Short heat because it was collected yesterday, Injected 200 uL.
T27	Oak	A	12	8/20/2008	8/19/2008	0	<100	0	0	8	Short heat because it was collected yesterday, Injected 200 uL.
T27		B		8/20/2008	8/19/2008	0	<100	0	0	8	Short heat because it was collected yesterday, Injected 200 uL.
T28	Oak	A	14	8/20/2008	8/19/2008	0	<100	0	0	8	Short heat because it was collected yesterday, Injected 200 uL.
T28		B		8/20/2008	8/19/2008	0	92	0	0	8	Short heat because it was

											collected yesterday, Injected 200 uL.
T30	Oak	A	10	8/20/2008	8/19/2008	0	0	0	0	8	Short heat because it was collected yesterday, Injected 200 uL.
T30		B		8/20/2008	8/19/2008	0	0	0	0	8	Short heat because it was collected yesterday, Injected 200 uL.
T31	Oak	A(not saved)	26	8/20/2008	8/20/2008		693	0	0	12	injected 200 uL .
T31		A		8/20/2008	8/20/2008		307	0	0		injected 200 uL .
T31		B1		8/20/2008	8/20/2008	29	142		0	12	injected 200 uL .
T31		B2		8/20/2008	8/20/2008	42	175	0	0	reheated 12 sec	injected 200 uL .
T32	Oak	A	14	8/20/2008	8/20/2008	5082	401	0	0	12	injected 200 uL .
T33	Oak	A	11	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T33		B		8/20/2008	8/20/2008	0	257	0	0	12	injected 200 uL .
T34	Oak	A	11	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .

Table 2. Concentrations of perchloroethylene (PCE) and other volatile organic compounds in tree-core samples collected from downtown and around Montgomery, Alabama, during August 2008--Continued.

[All concentrations in parts per billion by volume of vial headspace; nm, not measured; the method reporting level (MRL) for PCE, TCE, *cis*-1,2-DCE, and benzene was 2, 10, 15, and 10 parts per billion by volume (ppbv), respectively; core identifier refers to multiple cores collected from a particular tree]

Tree indentifier	Tree description	Core identifier	Diameter at Breast height (inches)	Analysis date	Core collected date	PCE ppbv	TCE ppbv	Cis-DCE ppbv	Benzene ppbv	Heating seconds	Comments
T34			**B33**	**8/20/2008**	**8/20/2008**	**0**	**0**	**0**	**0**	**12**	**injected 200 uL .**
T35	Oak	12	12	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T36		A	24	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T36		B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T37		A	17	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T37		B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T38	Ginko	A	16	8/20/2008	8/20/2008	44	0	0	0	12	injected 200 uL .
T38		B		8/20/2008	8/20/2008	trace(26)	0	0	0	12	injected 200 uL .
T39	Ginko	A	13	8/20/2008	8/20/2008	66	0	0	0	12	injected 200 uL .
T39		B		8/20/2008	8/20/2008	29	0	0	0	12	injected 200 uL .
T39		C(fruit)		8/20/2008	8/20/2008					12	injected 200 uL .
T40	Oak	A	22	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T40		B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T41	Oak	A	14	8/20/2008	8/20/2008	0	142	0	0	12	injected 200 uL .
T41		B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T41		C		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T42	Oak	A	13	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T43	Oak	A	14	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .

Table 2. Concentrations of perchloroethylene (PCE) and other volatile organic compounds in tree-core samples collected from downtown and around Montgomery, Alabama, during August 2008--Continued.

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Tree indentifier	Tree description	Core identifier	Diameter at Breast height (inches)	Analysis date	Core collected date	PCE ppbv	TCE ppbv	Cis-DCE ppbv	Benzene ppbv	Heating seconds	Comments
T43		B	20	8/20/2008	8/20/2008	0	102	0	0	12	injected 200 uL .
T44	Oak	A	19	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T44		B	19	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T45	Oak	A	14	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T45		B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T46	Oak	A	14	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T46		B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T47	Oak	A	20	8/20/2008	8/20/2008	0	524	0	0	12	injected 200 uL .
T61	Oak	A	25	8/20/2008	8/20/2008	0	176	0	0	12	injected 200 uL .
T62	Oak	A	23	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T63	Oak	A	18	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T64	Oak	A	28	8/20/2008	8/20/2008	0	68650	573	0	12	injected 200 uL .
T68	Oak	A	8	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T70	Oak	A	10	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T70	Oak, laurel	B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T68	Oak	B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T65		A	12.5	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T65	Oak, live	B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T59		A	22	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T59	Oak, laurel	B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T60		A	13	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T60	Oak	B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T66		A	11.5	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T66	Oak, Laurel	B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .

Table 2. Concentrations of perchloroethylene (PCE) and other volatile organic compounds in tree-core samples collected from downtown and around Montgomery, Alabama, during August 2008--Continued.

[All concentrations in parts per billion by volume of vial headspace; nm, not measured; the method reporting level (MRL) for PCE, TCE, *cis*-1,2-DCE, and benzene was 2, 10, 15, and 10 parts per billion by volume (ppbv), respectively; core identifier refers to multiple cores collected from a particular tree]

Tree indentifier	Tree description	Core identifier	Diameter at Breast height (inches)	Analysis date	Core collected date	PCE ppbv	TCE ppbv	Cis-DCE ppbv	Benzene ppbv	Heating seconds	Comments
T67		B	13	8/20/2008	8/20/2008	0	wave	0	0	12	injected 200 uL .
T67		A		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T69	Oak	C(paper)	6	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T69		A		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T69		B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T55		A	14	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T55		B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T58		A	20	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T58		B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T57		A	13	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T57		B		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T47		B	20	8/20/2008	8/20/2008	0	891	0	0	12	injected 200 uL .
T56		A		8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T56		B	nm	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
Air				8/20/2008	8/20/2008	0	0	0	0		injected 200 uL .
T61		B	nm	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T62		B	23	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T63		B	nm	8/20/2008	8/20/2008	0	0	0	0	12	injected 200 uL .
T5			31	8/21/2008	8/19/2008	120.6	37	0	0	8	Short heat because it was collected a few days ago, injected 200 uL.
T53A			10	8/21/2008	8/20/2008	0	0	0	0	8	Short heat because it was collected a few days ago, injected 200 uL.

T52	A	38	8/21/2008	8/20/2008	0	0	0	0	8	Slight TCE peak-wave.

Table 2. Concentrations of perchloroethylene (PCE) and other volatile organic compounds in tree-core samples collected from downtown and around Montgomery, Alabama, during August 2008--Continued.

[All concentrations in parts per billion by volume of vial headspace; nm, not measured; the method reporting level (MRL) for PCE, TCE, *cis*-1,2-DCE, and benzene was 2, 10, 15, and 10 parts per billion by volume (ppbv), respectively; core identifier refers to multiple cores collected from a particular tree]

Tree indentifier	Tree description	Core location	Diameter at Breast height (inches)	Analysis date	Core collected date	PCE ppbv	TCE ppbv	Cis-DCE ppbv	Benzene ppbv	Heating seconds	Comments
T52		B	38	8/21/2008	8/20/2008	0	0	0	0	8	injected 200 uL .
T51		A	12	8/21/2008	8/20/2008	0	0	0	0	16	injected 200 uL .
T51		B		8/21/2008	8/20/2008	0	0	0	0	8	injected 200 uL .
T54		A	28	8/21/2008	8/20/2008	0	0	0			injected 200 uL .
T54		AR		8/21/2008	8/20/2008	0	0				
T54		AR2		8/22/2008	8/20/2008	0	0	0	toluene at 103	8	injected 200 uL .
T54		B		8/22/2008	8/20/2008	0	0	0	Toluene at 95		
T53		B1	10	8/22/2008		0	0	0	0		
T53		B2		8/22/2008		0	0	0	0		
T7		B	12.75	8/22/2008		0	0	0	0		
T48		A	13	8/22/2008		0	0	0	0		
				8/22/2008		0	0	0	0		
T49		B	12	8/22/2008		0	0	0	0		
T49		A		8/22/2008		0	0	0	0		
T50		A	13.5	8/22/2008		0	0	0	0		
T50		b		8/22/2008		0	0	0	0		
T32		B	14	8/22/2008		8782	0	0	0		
T64		B	28	8/22/2008			4657	30	0		

Table 3. Concentrations of inorganics in tree-core samples collected from downtown and around Montgomery, Alabama, during August 2008, in milligrams per kilogram (equivalent to parts per million).

[R, replicate; T, tree; ***5.95***, mean of 18 sample method detection limits]

Tree ID	Tree dia (inches)	Cl	Na	Cl/Na	Cr	Pb	P	Mg	K	Ca	Ru	Sr	Fe	Cu	Zn	S	Mn
MDL_{mean}		***5.95***	***67.1***		***1.11***	***1.56***	***10.6***	***45.6***	***4.94***	***11.6***	***1.87***	***2.47***	***0.94***	***0.41***	***0.43***	***7.66***	***0.94***
T32(R)	14	19.718	75	0.25	3.645	1.481	204	1790	1280	1660	5.5	11.5	538	1.6	2.7	186	27
T59	22	49.432	63.8	0.77	0.782	1.253	150	296	2240	1900	1.6	20	104	2.78	7.3	166	11.3
T29	8	31.859	63.8	0.49	1.955	1.501	422	919	1740	1710	9	19	113	0.4	7	159	4.4
T15	44	29.838	60.2	0.49	35.228	2.069	56	356	1570	1680	7.5	2.6	198	2.7	7.3	117	80
T64	28	27.591	66.6	0.4	4.788	1.324	320	552	1450	1460	1.7	7.6	304	2.4	3.8	107	22.8
T23	7	135.401	68	1.9	2.778	1.625	126	136	609	616	1.4	8	65	1.4	6.2	104	6.4
T25	13	4	65	0.06	3.14	1.266	77	822	1770	1060	1.8	7.9	201	3.6	8.8	97	9.6
T47	20	31.801	70	0.44	0.882	1.634	237	348	2110	1570	2.1	10.4	58	2	3.2	150	23.7
T31	26	32.112	67	0.47	3.679	1.451	411	216	1250	2740	6.6	15.6	119	3.7	7.4	156	7
T44	19	4.2	66	0.06	3.163	1.476	81	266	1230	2180	1.6	18.5	53	1.1	3.4	94	10
T17	13	5.1	74	0.06	6.12	1.944	134	489	1560	6170	1.7	32.7	174	5.9	9.3	186	5
T3	23	44.007	65	0.67	4.713	1.59	163	362	1270	914	1.9	10	226	2.5	4.7	264	3.9
T6	17	12.761	66	0.18	2.897	1.584	52.5	271.8	368	941	1.5	10.2	235.7	7.3	3.7	135.7	6.9
T21	17	26.968	68	0.38	0.861	1.771	469	511	1630	1930	2	7.9	94	2.2	3.3	136	19
T35	12	68.032	71	0.95	2.511	1.554	807	1190	1910	2860	1.9	19.4	66.8	1.1	4.1	149	12
T40	22	4.2	68	0.06	0.85	1.298	42	310	881	1550	1.5	9	60	1.6	1.8	107	10.3
T32	14	29.203	66	0.43	0.909	1.755	375	225	1740	1170	7.3		131	0.4	4.1	240	14.3
T62	23	16.98	59	0.27	0.891	1.534	113	363	2060								

Table 4. Field Parameters, groundwater, April–May 2009
[S, shallow well; I, intermediate well]

Well Name	Sample Date	Sample Time	Well Depth	TOC elevation, ft above MSL	Depth to Water from TOC	Elevation of groundwater, ft AMSL	Hach - Dissolved Oxygen	Hach-Sulfide	Hach-Sulfate	Hach-Nitrate	Hach-Ferrous Iron	Hach-Turbidity	YSI Meter - Temperature	YSI Meter - Dissolved Oxygen	YSI Meter - Specific Conductance	YSI Meter - pH
			feet	feet AMSL	feet	feet AMSL	mg/L	mg/L	mg/L	mg/L	mg/L	ntu	degrees Celsius	mg/L	microsiemens/cm	pH units
1S	05/19/09	11:35	51.96	189.37	39.59	149.78	5.0	0	7	3.2	0	0.43	22.35	5.11	266	7.3
1I	05/12/09	11:30	141.76	190.00	40.52	149.48	4.4	0.01	1	2.9	0	3.61	20.87	5.55	64	7.7
2S	04/07/09	15:00	59.87	188.59	42.20	146.39	6.3	0	8	6.3	0.05	0.8	21.85	5.9	212	5.2
4S	04/21/09	9:30	38.75	178.72	32.24	146.48	6.4	0	19	4.5	0	1.3	21.54	4.9	322	5.6
5I	04/08/09	13:10	159.87	210.98	59.52	151.46	6.6	0	1	2.2	0	0.6	21.75	5.4	60	5.8
7S	04/09/09	11:15	96.71	179.65	35.61	144.04	4	0	4	1.5	0.04		21.81	2.6	70	5.8
7I	04/09/09	14:40	128.85	179.76	35.57	144.19	6.4	0	6	6.6	0	1.7	22.06	6.9	212	5.2
8S	04/20/09	11:40	51.77	173.46	35.92	137.54	5.9	0	9	6.1	0	0.5	22.25	6.6	219	5
8I	04/21/09	13:40	119.73	173.42	35.90	137.52	3.6	0	2	1.7	0.05	0.8	21.34	3.35	72	6
9S	04/27/09	14:00	71.76	213.41	56.23	157.18	5.5	0	6	1.5	0	0.2	22.99	6	177	5.1
10S	04/27/09	10:15	71.91	212.67	57.81	154.86	5.1	0	13	6.4	0	0.5	22.69	5.2	249	5.3
12S	04/23/09	11:30	41.88	157.58	25.00	132.58	5.5	0	5	7.1	0.02	0.1	22.04	4.9	254	5.5
12I	04/22/09	12:35	104.69	157.82	25.02	132.80	2.2	0	3	0.7	0.12	0.8	21.22	1.8	91	6.1

Table 5. VOCs in groundwater, April–May 2009
[Mean reporting levels as shown in *black*]

Well name	THMs	1,1,1,2-Tetrachloro ethane, water	CFC-113	1,1-DCA	1,1-DCE	1,2-Dichlorobenzene	1,2-DCA	Benzene	cis-1,2-DCE	Dichloromethane	Diethyl ether	DIPE	MTBE	PCE
1S	37.3	*0.04*	*0.04*	0.04	0.049(E)	0.02	0.06	0.016	0.02	0.04	0.12	0.06	0.15	5.28
1I		*0.04*	*0.04*	0.04	0.02	0.02	0.1	0.02	0.02	0.04	0.1	0.06	0.1	0.07(E)
1I(R)		*0.04*	*0.04*	0.04	0.02	0.02	0.1	0.02	0.02	0.04	0.1	0.06	0.1	0.08(E)
2S	3	*0.04*	*0.04*	0.04	0.09(E)	0.02	0.1	0.02	0.02	0.04	0.1	0.06	0.1	25
4S	2	0.07(E)	0.18	0.04	0.02	0.03(E)	0.3	0.01(E)	18.8	M	0.1	0.22	0.1	84.8
5I		*0.04*	*0.04*	0.04	0.02	0.02	0.1	0.02	0.02	0.04	0.1	0.06	0.1	7.77
7S		*0.04*	*0.04*	0.04	0.02	0.02	0.1	0.02	0.02	0.04	0.1	0.06	0.1	0.07(E)
7I	1	*0.04*	*0.04*	0.04	0.02	0.02	0.1	0.02	0.02	0.04	0.1	0.06	0.1	0.06(E)
8S		*0.04*	*0.04*	0.04(E)	1.68	0.02	M	0.02	0.02	0.04	0.1	0.06	0.1	18.8
8I		*0.04*	*0.04*	0.04	0.02	0.02	0.1	0.02	0.02	0.04	0.1	0.06	0.1	0.01(E)
9S	3	*0.04*	0.07(E)	0.04	0.13	0.02	0.1	0.02	0.02(E)	0.04	0.1	0.06	0.1	0.03(E)
10S	1	*0.04*	*0.04*	0.04	0.02	0.02	0.1	0.02	0.02	0.04	0.1	0.06	0.1	0.07(E)
12S		*0.04*	0.08(E)	0.04	0.02	0.02	0.1	0.02	0.18	0.04	0.1	0.22	0.7	63.8
12I		*0.04*	*0.04*	0.04	0.02	0.02	0.1	0.02	0.02	0.04	0.1	0.06	0.1	0.01(E)

Table 5. VOCs in groundwater, April–May 2009-continued

CCl_4	Toluene	trans-1,2-DCE	TCE	CFC-11	TCM	VC
0.06	0.018	0.018	0.061(E)	0.08		0.08
0.06	0.02	0.02	0.02	0.08	0.03(E)	0.1
0.06	0.02	0.02	0.02	0.08	0.04(E)	0.1
0.06	0.03(E)	0.02	0.1	0.06(E)	2.65	0.1
0.06	0.02	0.18	9.62	0.08(E)	1.96	0.1
0.06	0.02	0.02	0.51	0.08	0.04	0.1
0.06	0.02	0.02	0.02	0.08	0.04	0.1
0.18	0.02	0.02	0.02	0.08	1.28	0.1
0.18	0.02	0.02	0.51	0.25	0.6	0.1
0.06	0.02	0.02	0.02	0.08	0.04	0.1
0.06	0.02	0.02	0.03(E)	0.07(E)	2.98	0.1
0.06	0.02	0.02	0.02	0.08	1.01	0.1
0.06	0.01(E)	0.02	0.24	0.08	0.71	0.1
0.06	0.02	0.02	0.02(E)	0.08	0.04	0.1

Table 6. Inorganics in groundwater, April–May 2009
(MRL, mean reporting limit)

Well name	Depth of well, feet below land surface datum	Ca,mg/L	Mg,mg/L	K,mg/L	Na, mg/L	Al, ug/L	As, ug/L	Ba, ug/L	Be, ug/L
1S	51.96	11.8	5.33	4.21	21	10.7	0.14(E)	63	0.2
1I	141.76	4.38	0.415	1.53	4.98	21.7	0.21	34.9	0.2
2S	59.87	10.5	4.13	3.5	18.9	32	0.2	69.4	0.2
4S	38.75	7.09	3.3	13	45.1	14	0.2	55.9	0.13(E)
5I	159.37	4.26	0.58	2.04	4.8	6(E)	0.2	25.4	0.2
7S	96.71	3.91	0.512	1.74	8.5	110	0.2(E)	17.8	0.2
7I	128.85	13.5	2.71	3.2	16.2	6	0.2	133	0.23
8S	51.77	12	3.61	4.82	18.8	9	0.2	68.1	0.15(E)
8I	119.73	5.51	0.61	1.78	6.2	15	0.2	35.9	0.2
9S	71.76	6.57	3.58	2.71	14.9	6.2	<.2	127	<0.2
10S	71.91	8.73	3.76	2.39	25.6	8.4	<.2	56.9	<.2
12S	41.88	16.8	4.34	4.34	18.5	4	0.2	106	0.2
12I	104.69	6.2	0.795	2.08	11	220	0.48	18.9	0.2
MRL		*0.04*	*0.008*	*0.2*	*0.4*	*6.0*	*0.2*	*0.6*	*0.2*
	National Primary Drinking Water Standard	-	-	-	-	-	*10.0*	*200.0*	*4.0*
	National Secondary Drinking Water Standard	-	-	-	-	*200.0*	-	-	-

Table 6. Inorganics in groundwater, April–May 2009, continued

Cd, ug/L	Cr, ug/L	Co, ug/L	Cu, ug/L	Fe, ug/L	Pb, ug/L	Li, ug/L	Mn, ug/L	Hg, ug/L	Mo, ug/L	Ni, ug/L	Se, ug/L	Ag, ug/L	Sr, ug/L	Zn ug/L
0.071	6.1	0.122	2.2(E)	22.2	0.157	1.21	6.67	0.009	0.112	9.5	2.07	0.06	98.8	4.5
0.15	3.69	0.123	<4	27.9	.077(E)	1.01	3.97	0.01	0.186	8.1	0.09(E)	<0.06	61.8	<4
0.04(E)	3.5	0.1	218	28	1.13	1	13	0.011	0.1	3	2.6	0.06	74.4	11
0.06	1.2	0.25	101	12(E)	0.18	M	18.7	0.01	0.1	1.1	3.3	0.06	54	4
0.06	2.4	0.1	30	9(E)	0.31	2	0.9	0.01	0.1	0.61	0.12	0.06	73.7	4
0.05(E)	1.4	0.27	4	75	0.34	2	26.7	0.01	0.2	4.6	0.06(E)	0.06	87.6	4(E)
0.06	5.1	0.1	98	15	0.45	1	2.7	0.01	0.1	2.3	5.6	0.06	146	9
0.11	3.3	0.1	40	20	0.91	2	15	0.01	0.1	3.5	1.9	0.06	120	6
0.06	9.4	0.24	28	128	0.11	3	6.8	0.01	0.1	18.5	0.09(E)	0.06	97.1	4
0.074	2.45	<.1	<4	10.7(E)	0.103	0.911	7.58	0.01	<.1	3.37	1.69	<0.06	59.6	3.2(E)
0.045(E)	3.13	.053(E)	15.7	12.2(E)	0.131	0.828	4.65	0.01	<.1	1.73	3.09	<.06	47.7	2.9(E)
0.13	3	0.06(E)	50	14	0.16	2	1.8	0.01	0.1	4.6	2.1	0.06	118	12
0.06	2.1	0.4	14	300	0.13	4	74.5	0.01	0.7	2.9	0.22	0.06	127	4
0.06	*0.4*	*0.1*	*4.0*	*14*	*0.1*	*0.08*	*0.4*	*0.01*	*0.1*	*0.2*	*0.12*	*0.06*	*0.8*	*4*
5.0	*100.0*	-	*1,300.0*	-	*15.0*	-	-	*2.0*	-	-	*50.0*	-	-	-
-	-	-	-	*300.0*	-	-	*50.0*	-	-	-	-	*100.0*	-	*500.0*

Table 7. Timeline of events important to the Commercial Print Industry, 1436–2010.

[[1]ATSDR accessed 10/1/2008; [2]Black & Veatch 2002; [3]Malcolm Pirnie, Inc., 2003; [4]Envrionmental Materials Consultants, Inc., 2003; [5]JM Hall SEA, 2007; [6]this report; [7]Scott and others 1987.]

Date[1]	Event
200	Woodblock printing.
1436	Printing press invented by Johannes Gutenberg.
1640s	Monotype letterpress invented by Giovanni Castiglione.
1728	Ben Franklin prints Poor Richard's Almanack in Philadelphia.
1796	Lithography invented by Alois Senefelder.
1875	Offset printing on metals invented by Robert Barclay.
1886	Linotype invented by Ottmar Mergenthaler.
1903	Offset printing on paper invented by Ira Rubel. Print roller and paper are offset by rubber blanket roller.
1960s	Commercial Printing Industry switches from flammable alcohol-based solvents to non-flammable chlorinated solvents, such as TCE and PCE, to accelerate drying times in the pressroom.
1990s	Commercial Printing Industry switches to vegetable-oil and water-based solvents and inks.

[1]Table footnote

Table 8. Listed Wastes and Toxicity Characteristic Contaminants Found in the Commerical Printing Industry (USEPA 1997b)

Waste Code	Waste (only major chemicals are listed)
F001	Spent halogenated solvents
	PCE
	TCE
	1,1,1-TCA
	CFC-113
F002	Spent halogenated solvents
	PCE
	TCE
	1,1,1-TCA
	CFC-113s
F003	Spent non-halogenated solvents
	Xylene
	Toluene
	Methanol
F005	Spent non-halogenated solvents
	Toluene
	MEK
D005	Barium
D007	Chromium
D011	Silver

Table 9.Timeline of events of the Commercial Printing Industry important to the assessment of the Capital City Plume Site, Montgomery, Alabama, 1819–2010.

[[1]ATSDR accessed 10/1/2008; [2]Black & Veatch 2002; [3]Malcolm Pirnie, Inc., 2003; [4]Envrionmental Materials Consultants, Inc., 2003; [5]JM Hall SEA, 2007; [6]this report; [7]Scott and others 1987; [8]Muskat, 1985.]

Date[1]	Event
1819	City of Montgomery incorporated.
1828–29	A major Montgomery newspaper founded.
1833	Major newspaper changed name.
–1850	A major Montgomery newspaper located on Commerce Street[8].
1855	Building constructed at 200 Dexter Avenue and occupied by a major Montgomery newspaper.
1860s	Stormwater sewer system built in Montgomery[1].
1885	Montgomery municipal water supplied by well fields[1].
1940–41	A major Montgomery newspaper moves from 200 Dexter Avenue to 200 Washington Street, the former location of a competing newpaper. Location used as a press room. The newspaper operates an 8-unit Goss Headliner *letter press* and made zinc plates on site.
1960s	Commercial Printing Industry switches from flammable alcohol-based solvents to non-flammable chlorinated solvents, such as TCE and PCE, to accelerate drying times in the pressroom.
1962	Public supply well 9W drilled in the shallow aquifer, screened from 69 to 79 ft bls[2,7].
1970	Montgomery sewage previously discharged to the Alabama River now sent to Econchate Waste water treatment plant.
1970s	A major Montgomery newspaper made aluminum plates on site at 200 Washington Street. A commercial company used to launder soiled rags off site.
1977	A major Montgomery newspaper operates a 9-unit lithographic offset press, which uses an ink and water mixture.
1991–92	PCE at 7.1 µg/L detected in public supply well 9W in April 1991 and PCE at 21 µg/L in

	wells 9W and 9E in May 1992, both in the shallow aquifer; MWWSSB[2].
September 1993	Workers overcome by vapors during soil excavation at about 25 ft bls for RSA Energy Plant[2]. (Contaminated soil excavated and removed[2].)
October 1993	ADEM Phase I Investigation[2].
November 1993	ADEM Phase II Investigation[2].
February 1995	ADEM Preliminary Assessment confirms detection of PCE in shallow groundwater near the RSA Energy Plant[2].
1996	The RSA Tower is built near RSA Energy Plant.
1997	A major Montgomery newspaper stops printing at 200 Washington Street.
1999	The MWWSSB confirms presence of PCE in shallow groundwater[2].
2000	USEPA begins a Remedial Investigation (RI)[2].
2002	A major Montgomery newspaper moves from 200 Washington Street to 425 Moulton Street.
2003	City of Montgomery begins Feasibility Study[3]. The Montgomery County Commission initiates an Environmental Site Assessment of 200 Washington Street, the former location of a major Montgomery Newspaper[4].
2007	City of Montgomery initiates a groundwater samping event that indicates PCE remains in wells[5].
August 2008	The USEPA and USGS conduct an assessment of potential sources of groundwater ontamination[6].
January 2009	The USEPA and USGS conduct an assessment of the probable release history of groundwater ontamination[6].

April–May 2009	USEPA and USGS collect groundwater samples from wells at the CCP Site.
May 2010	USEPA collects groundwater samples; USGS analyzes for CFCs and SF_6.
December 2010	This report[6].

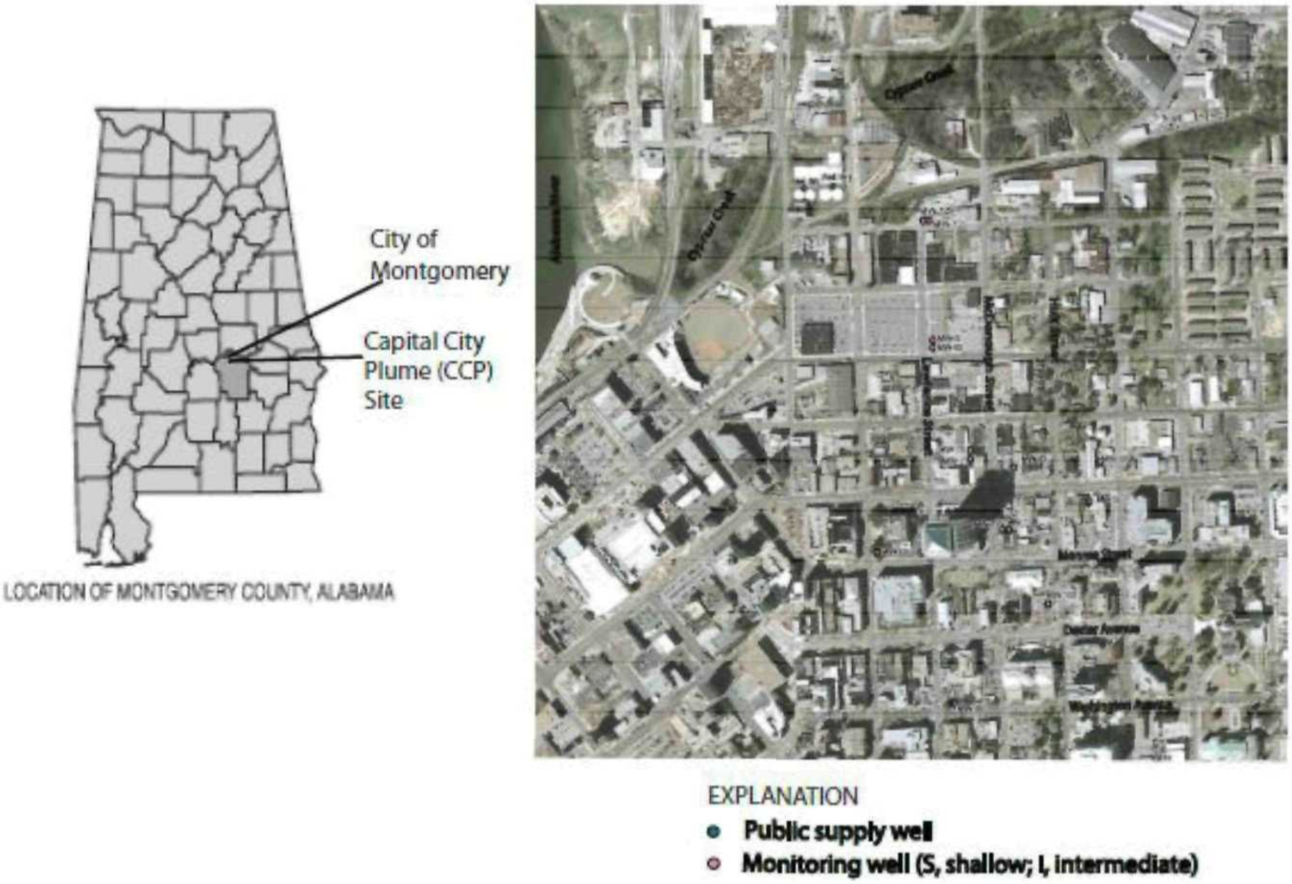
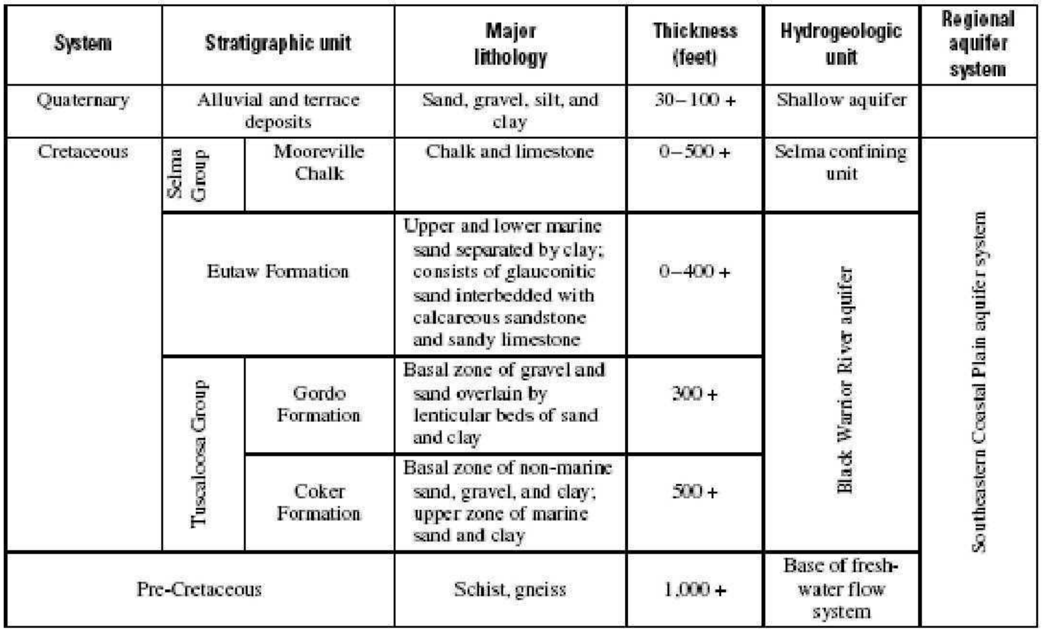


Figure 1. Location of Montgomery County, the City of Montgomery, the Capital City Plume (CCP) Site, and existing public supply and shallow (S) and intermediate (I) monitoring wells related to the Capital City Plume (CCP) Site (modified from Robinson 2002).



System	Stratigraphic unit		Major lithology	Thickness (feet)	Hydrogeologic unit	Regional aquifer system
Quaternary	Alluvial and terrace deposits		Sand, gravel, silt, and clay	30– 100 +	Shallow aquifer	
Cretaceous	Selma Group	Mooreville Chalk	Chalk and limestone	0– 500 +	Selma confining unit	Southeastern Coastal Plain aquifer system
	Eutaw Formation		Upper and lower marine sand separated by clay; consists of glauconitic sand interbedded with calcareous sandstone and sandy limestone	0–400 +	Black Warrior River aquifer	
	Tuscaloosa Group	Gordo Formation	Basal zone of gravel and sand overlain by lenticular beds of sand and clay	300 +		
		Coker Formation	Basal zone of non-marine sand, gravel, and clay; upper zone of marine sand and clay	500 +		
Pre-Cretaceous			Schist, gneiss	1,000 +	Base of fresh-water flow system	

Figure 2. Generalized stratigraphic and hydrogeologic units underlying Montgomery, Alabama and the Capital City Plume (CCP) Site (modified from Robinson 2002).

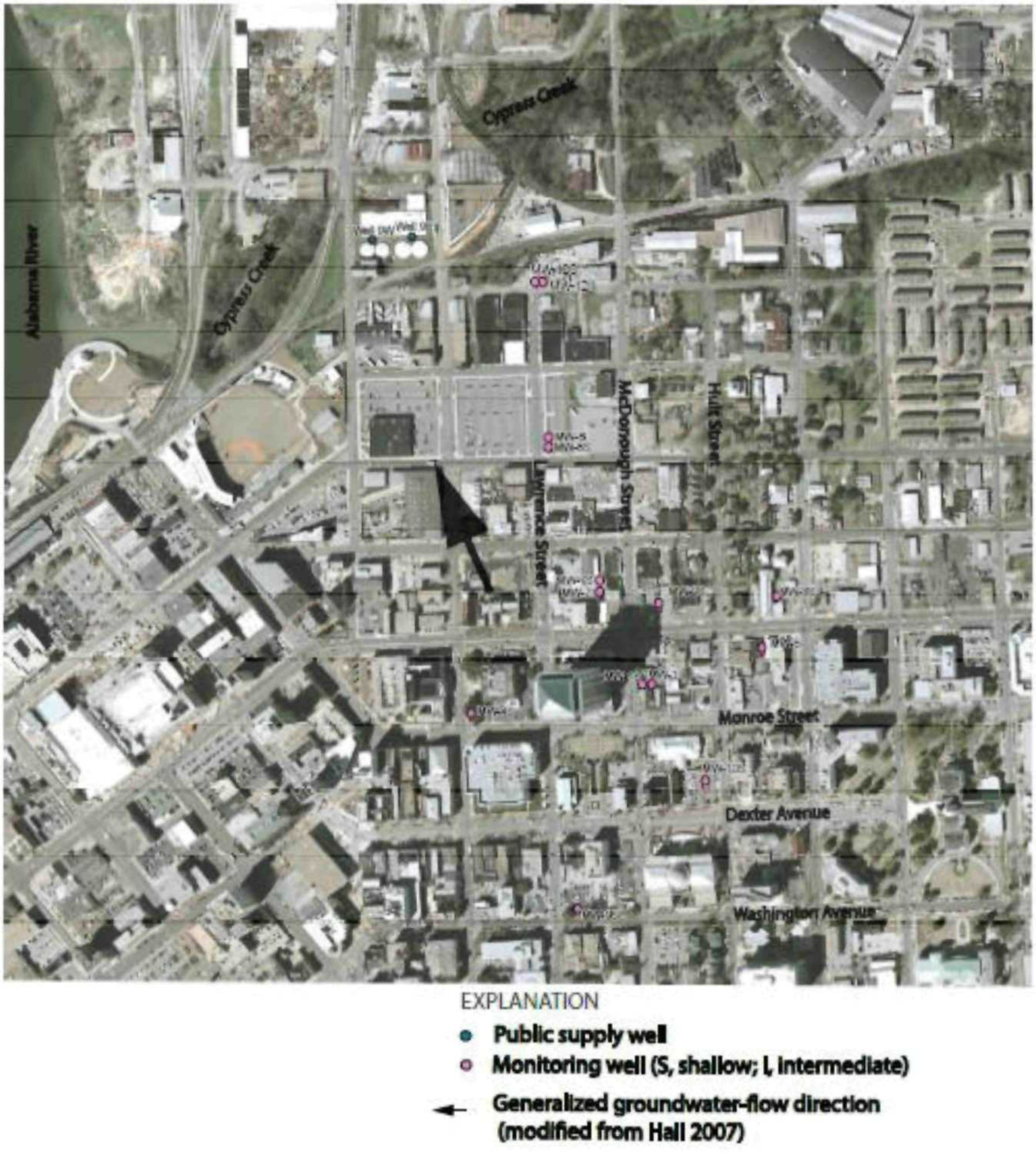


Figure 3. Location of public supply and shallow (S) and intermediate (I) monitoring wells and generalized groundwater-flow direction at the Capital City Plume (CCP) Site, July 2007, Montgomery, Alabama (modified from Hall 2007).

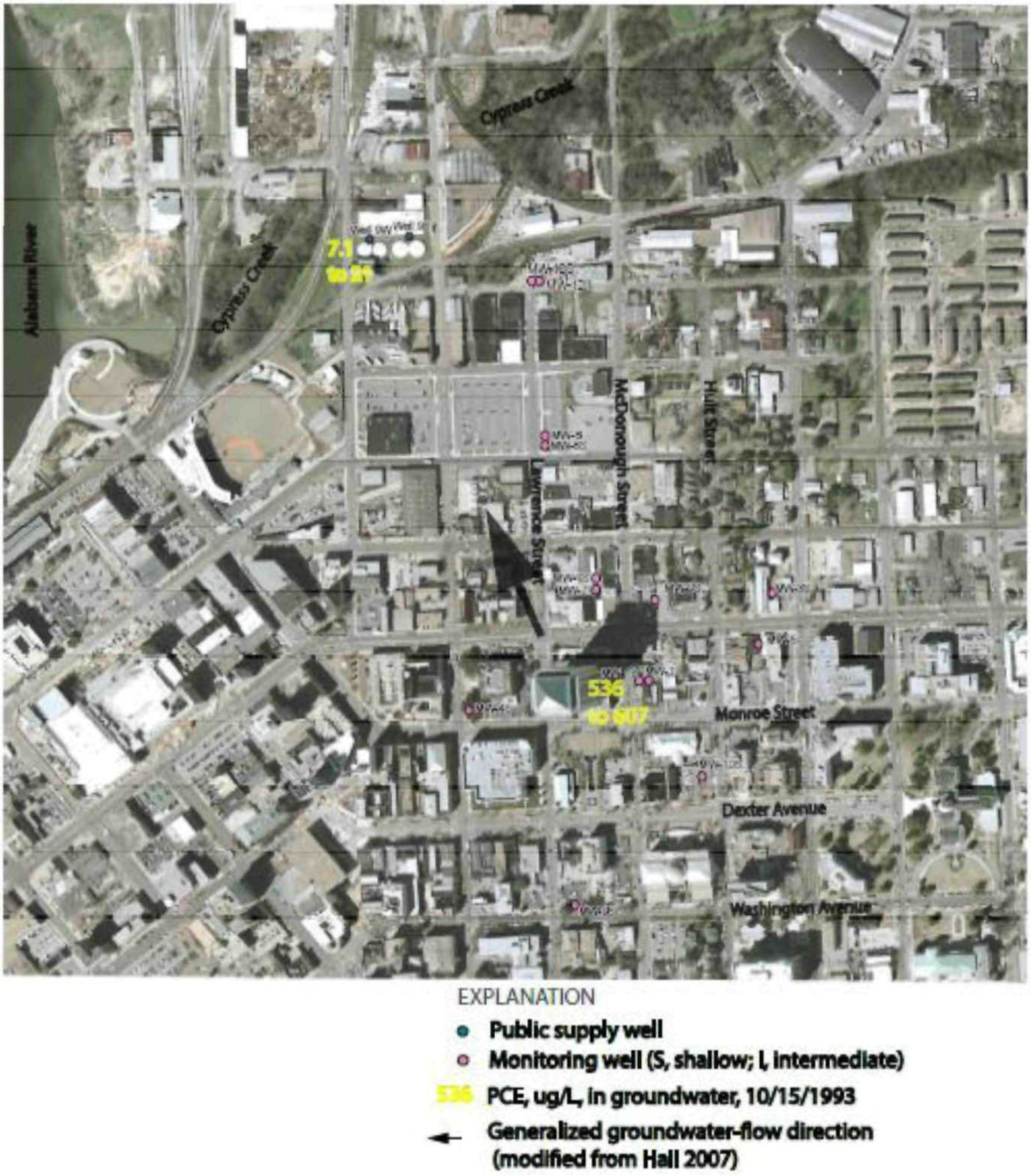


Figure 4. –Locations of existing monitoring wells and the approximate extent of the Capitol City Plume (CCP) Site as defined by PCE in groundwater,10/15/1993. All wells are shown but not necessarily available for sampling in 1993 (data from Black & Veatch 2002).

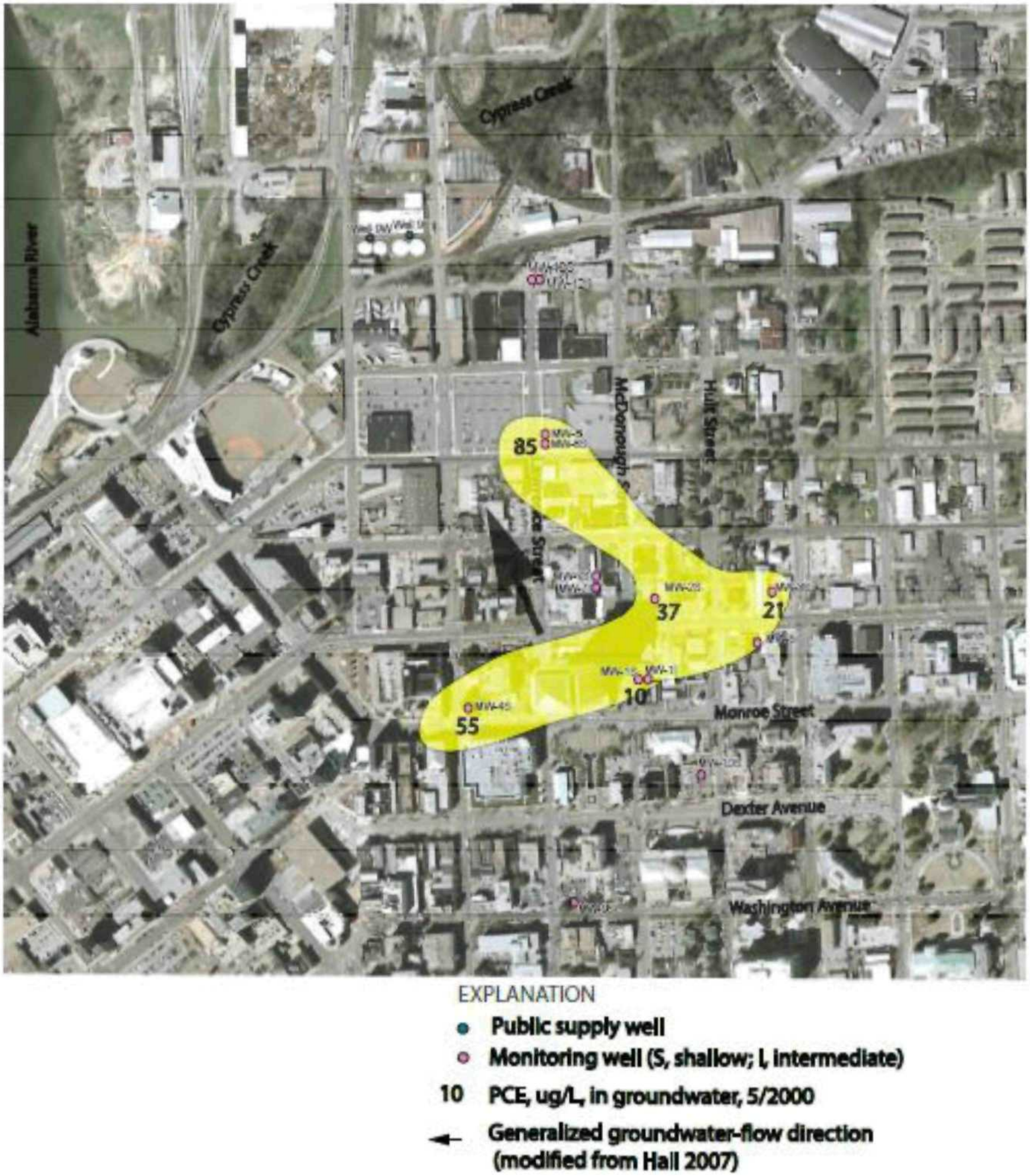


Figure 5. –Locations of existing monitoring wells and the approximate extent of the Capitol City Plume (CCP) Site as defined by PCE in groundwater, 5/2000 (modified from data presented in Black & Veatch 2002).

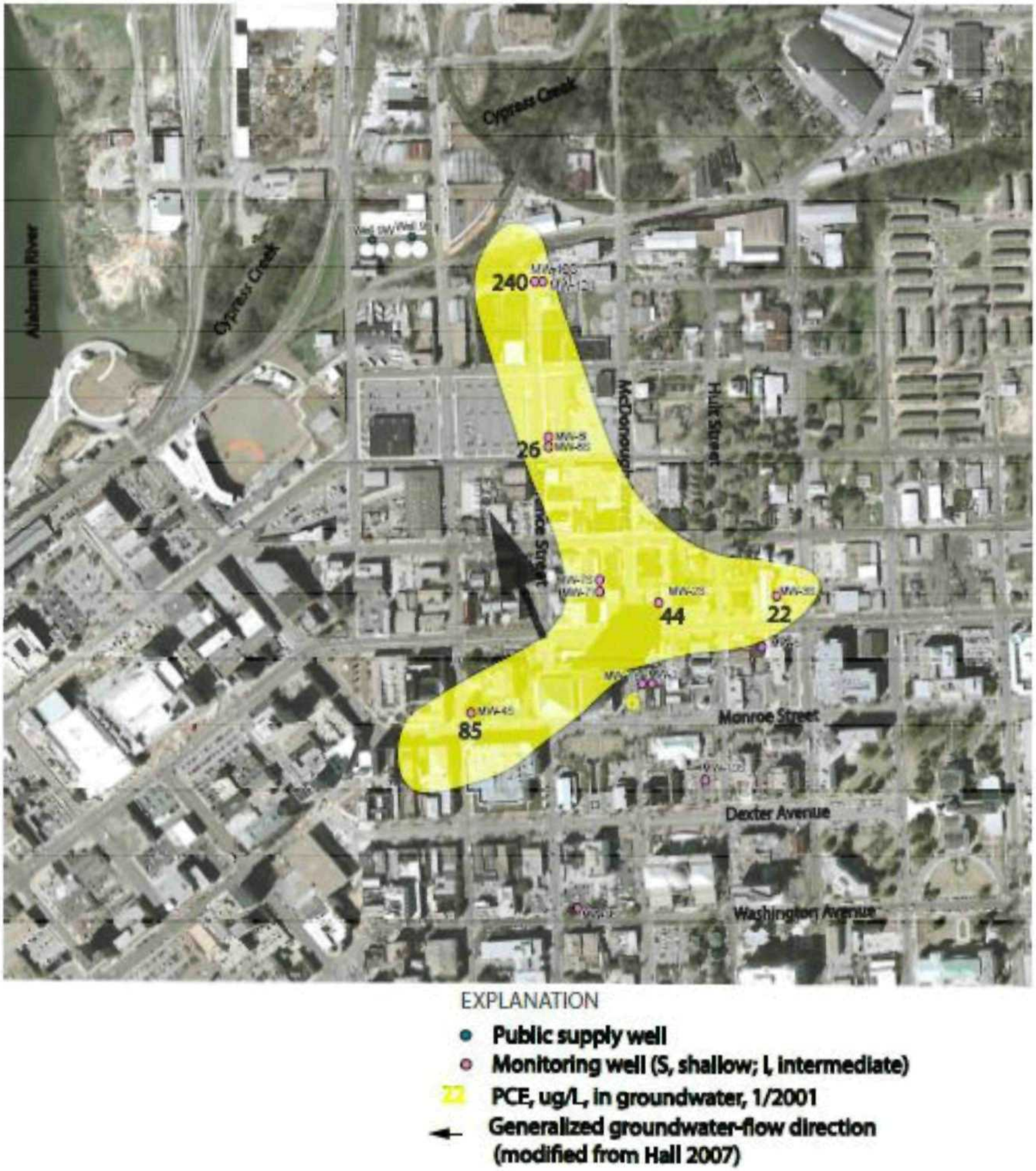


Figure 6. –Locations of existing monitoring wells and the approximate extent of the Capitol City Plume (CCP) Site as defined by PCE in groundwater, 1/2001 (modified from data presented in Black & Veatch 2002).

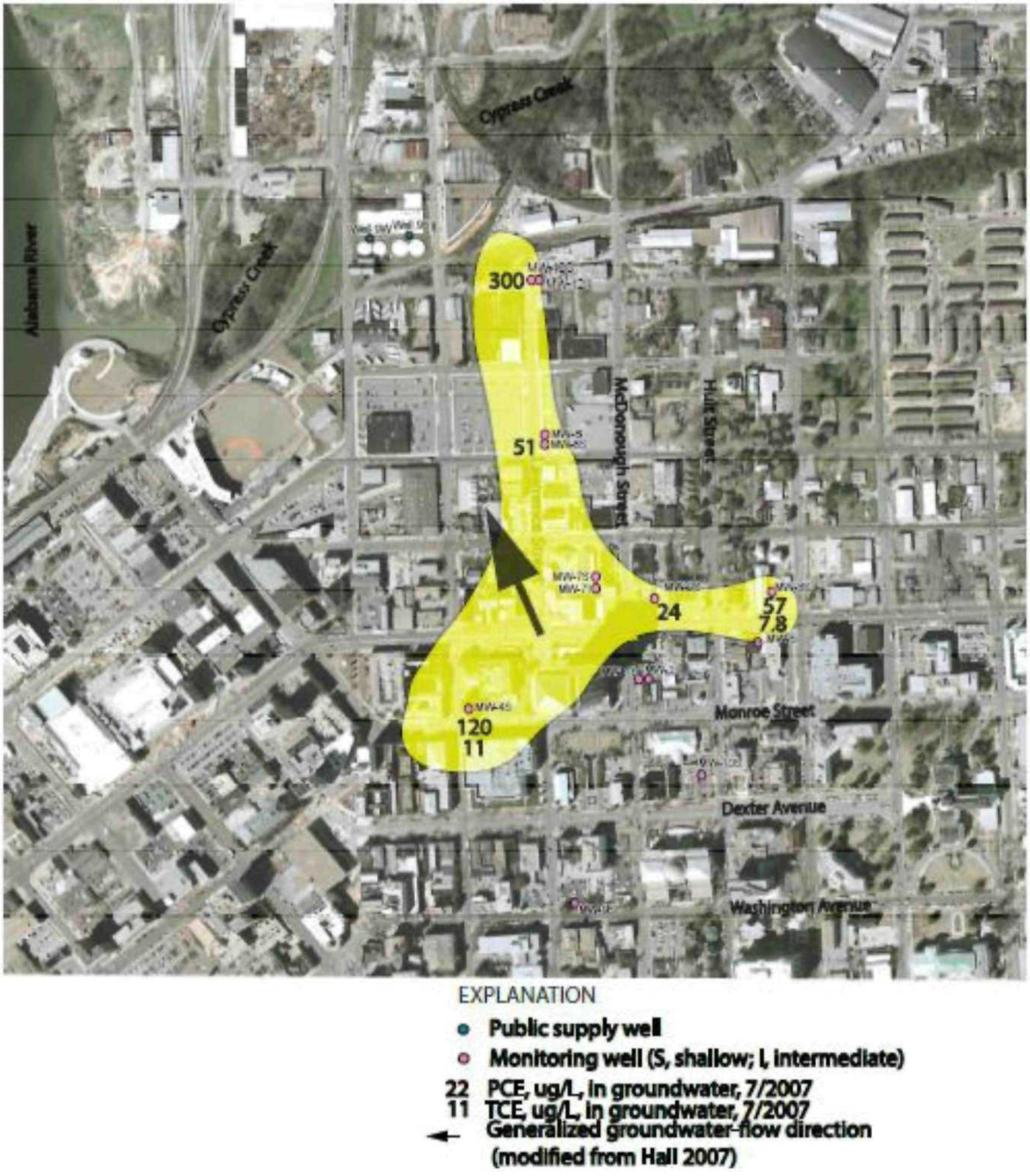


Figure 7. –Locations of existing monitoring wells and the approximate extent of the Capitol City Plume (CCP) Site as defined by PCE and TCE in groundwater, 7/2007 (modified from Hall 2007).

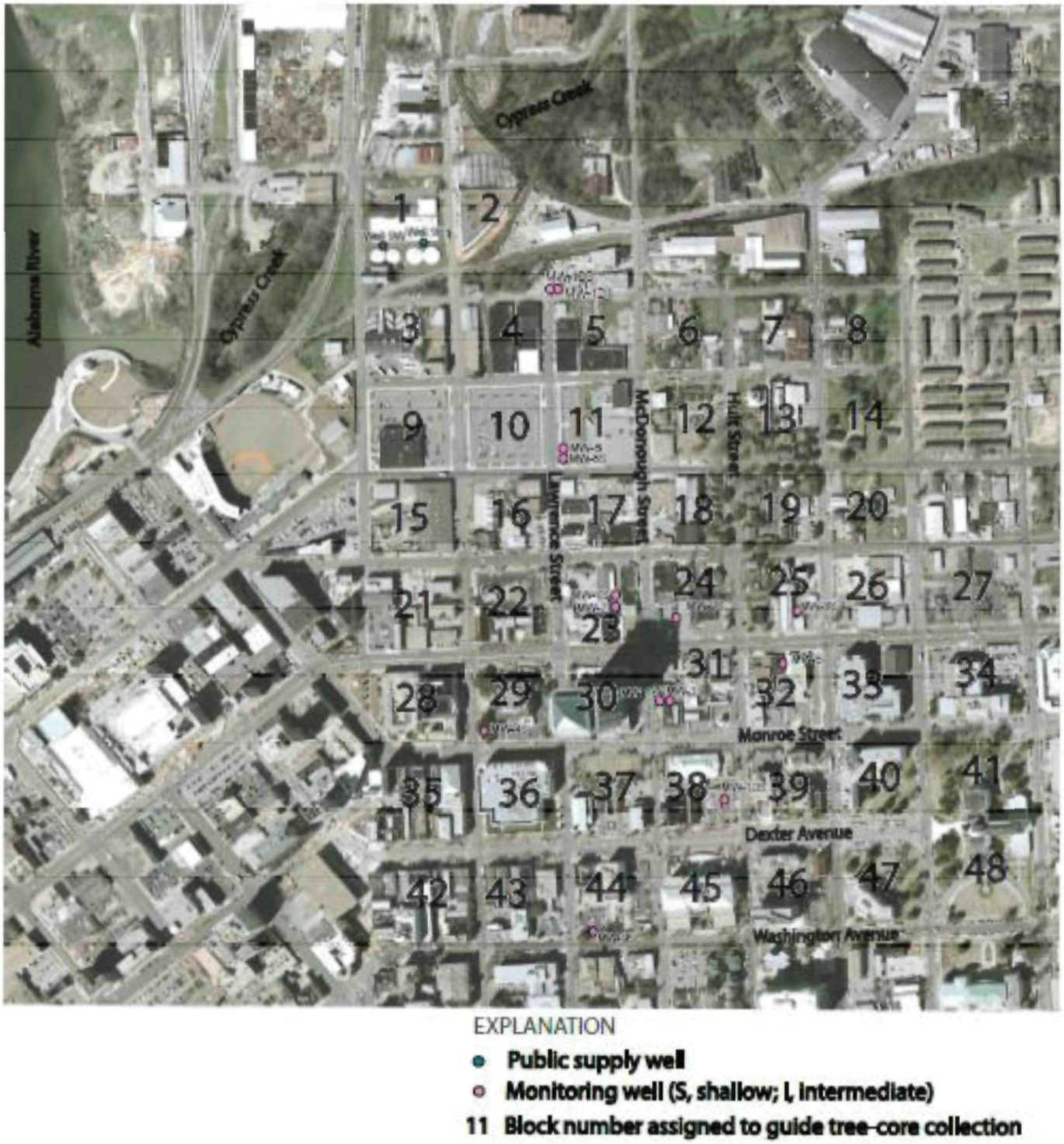


Figure 8. Grid system to guide tree-core collection in downtown Montgomery. These blocks selected for tree-core sampling are located within the City of Montgomery's local groundwater drainage basin as inferred from topographical highs.

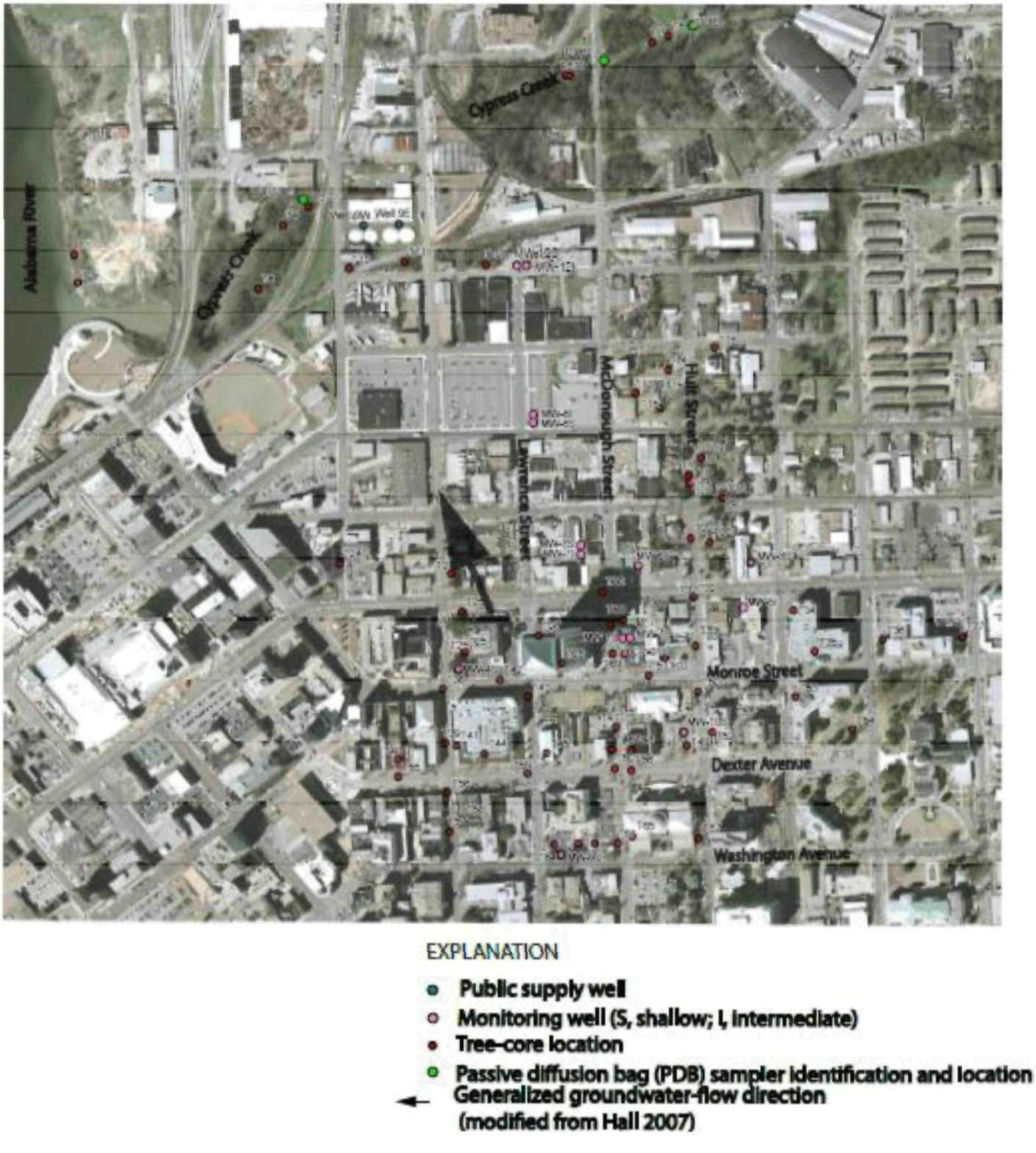


Figure 9. Locations of trees cored for VOCs and metals analysis in August 2008. Also shown are the locations of the three Passive Diffusion Bag samplers in Cypress Creek.

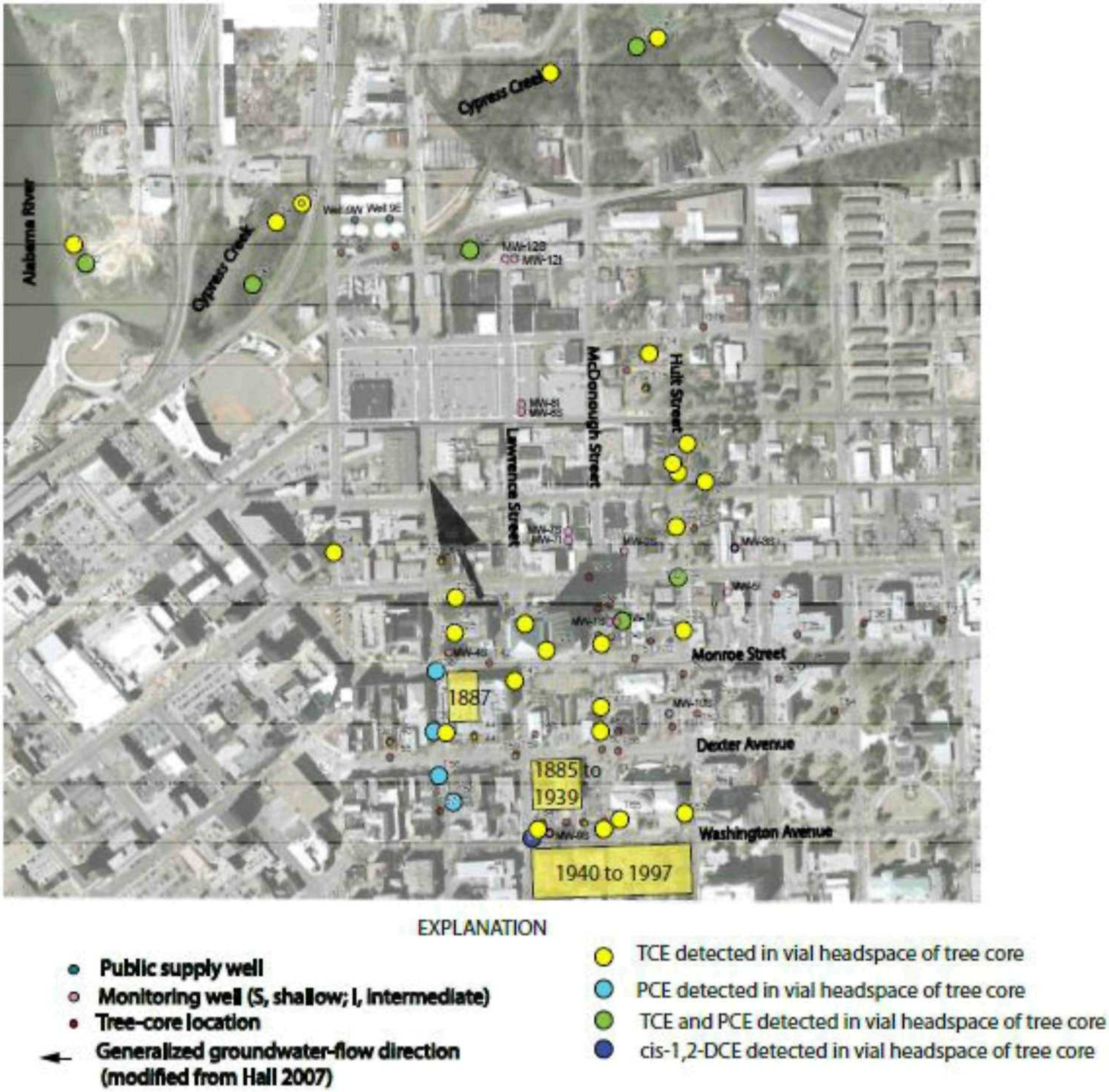


Figure 10. Locations of trees cored in August 2008 and trees shown that had VOCs detections above the MDL in tree-core headspace. The actual concentrations detected are shown in Table 4.The locations and dates of occupation of a major commercial printing industry since 1828 are shown.

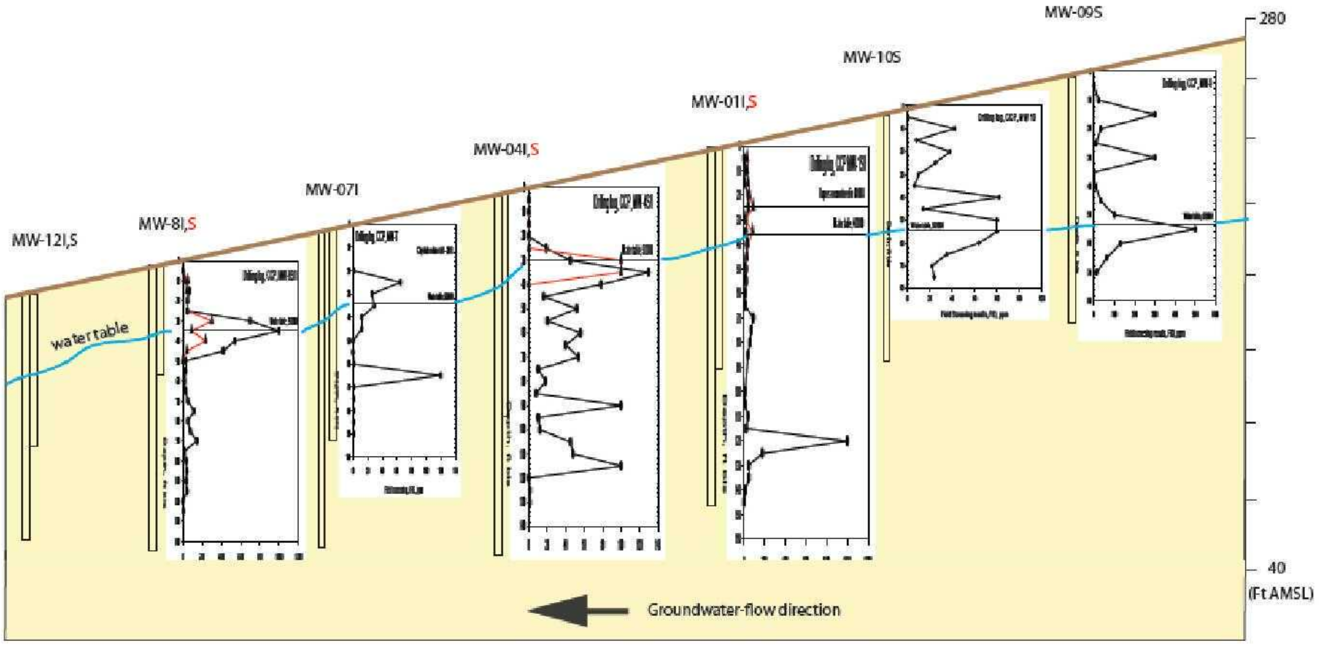


Figure 11. Cross section showing PID results for wells installed in 2000 during the USEPA RI (data from Black & Veatch 2002; data interpretation by USGS).

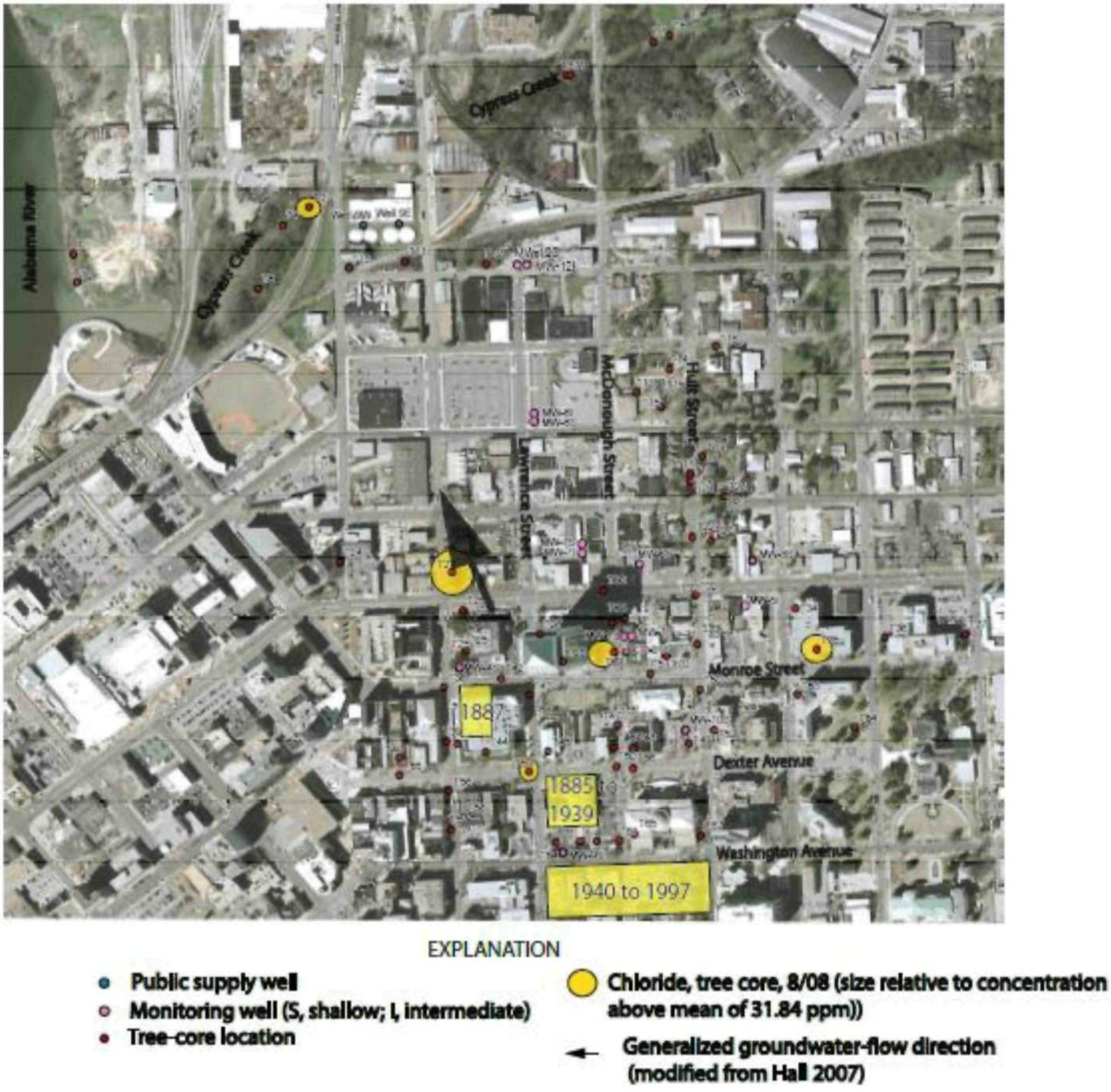


Figure 12a-. Results of PIXE analysis of chloride in tree cores, August 2008. Trees are depicted that had concentrations above the mean for all trees. The locations and dates of occupation of a major commercial printing industry are shown on this and all subsequent figures.

Figure 12b-. Results of PIXE analysis of chromium in tree cores, August 2008. Trees are depicted that had concentrations above the mean for all trees.

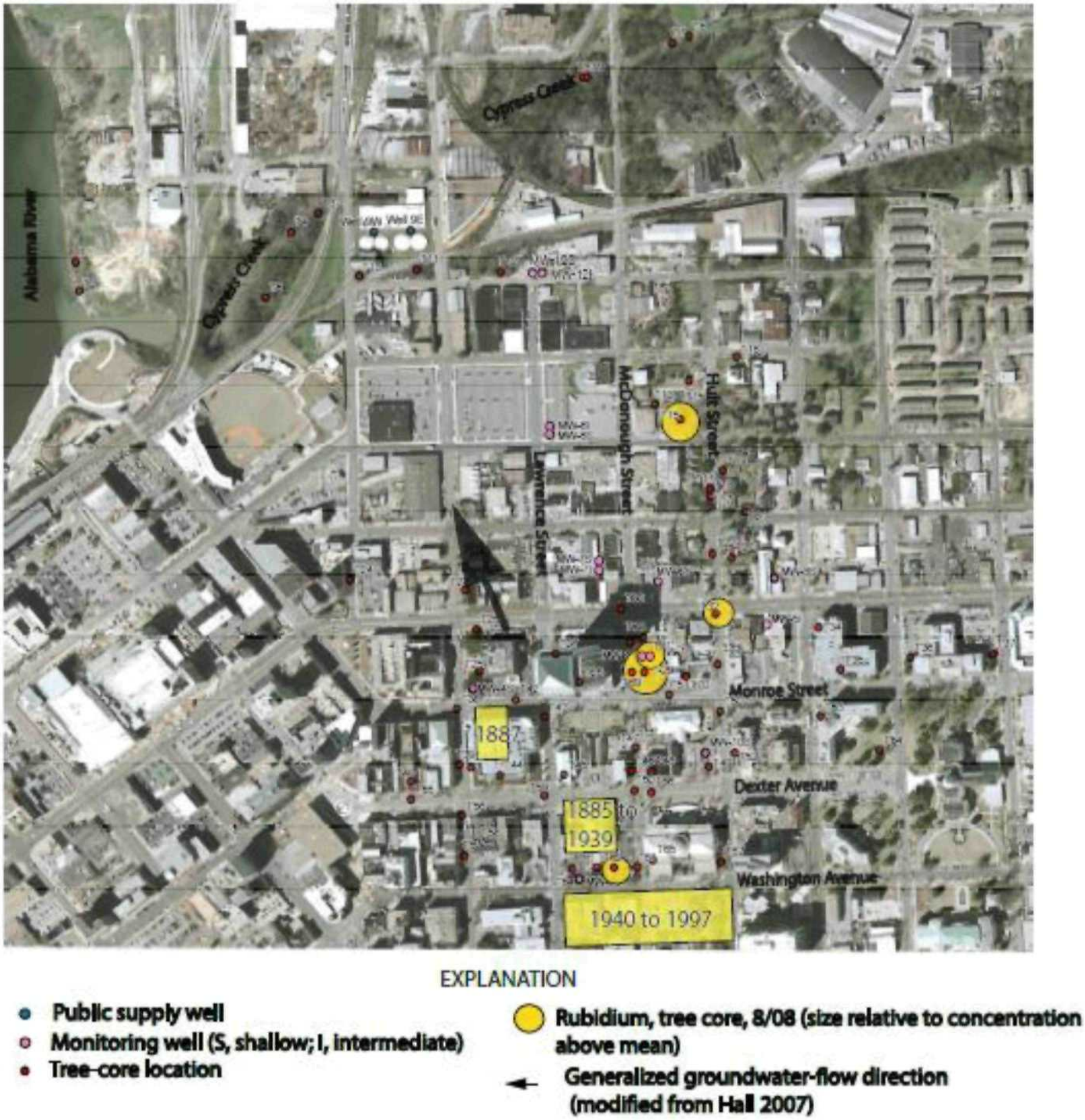


Figure 12c-. Results of PIXE analysis of rubidium in tree cores, August 2008. Trees are depicted that had concentrations above the mean for all trees.

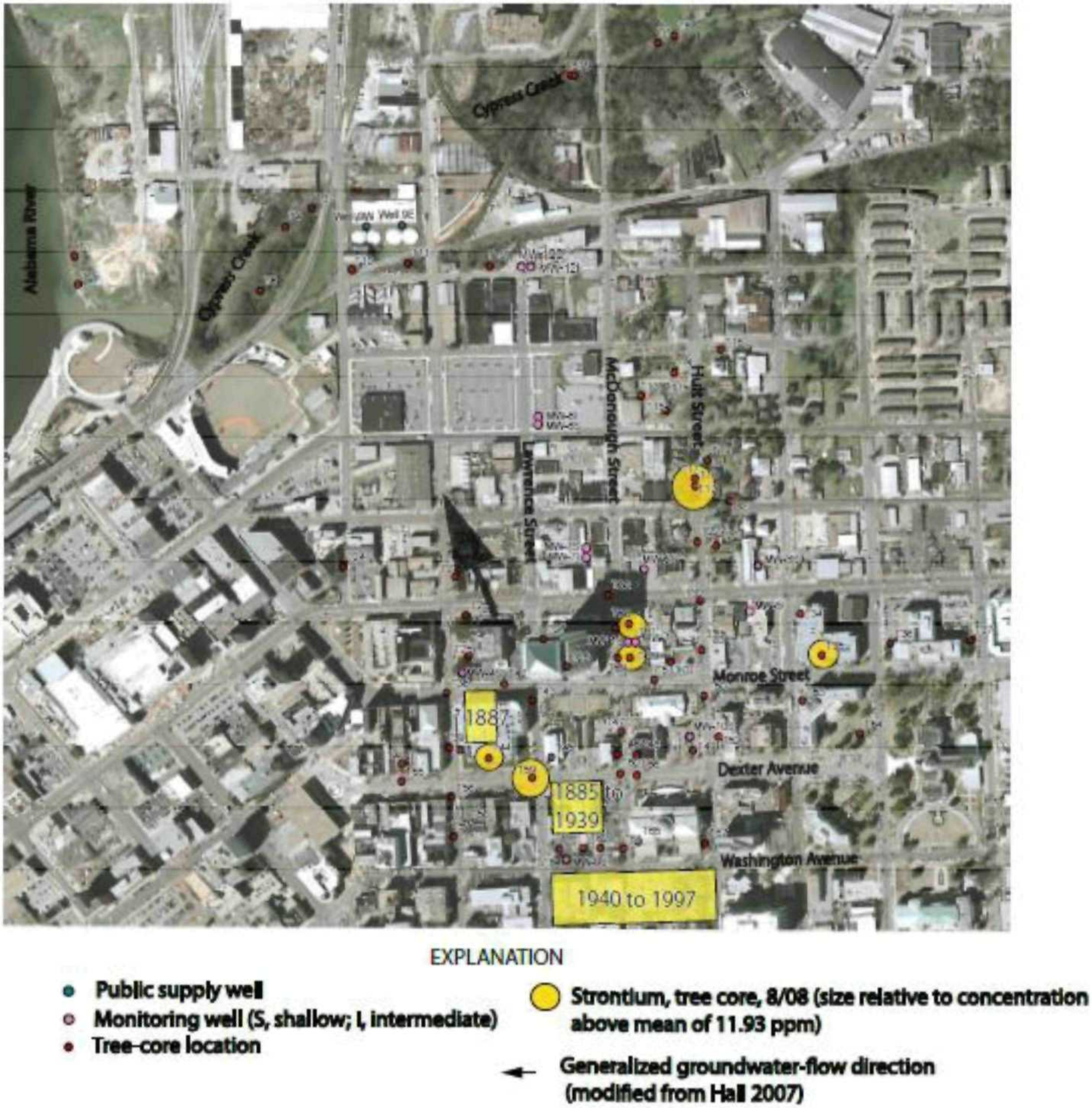


Figure 12d-. Results of PIXE analysis of strontium in tree cores, August 2008. Trees are depicted that had concentrations above the mean for all trees.

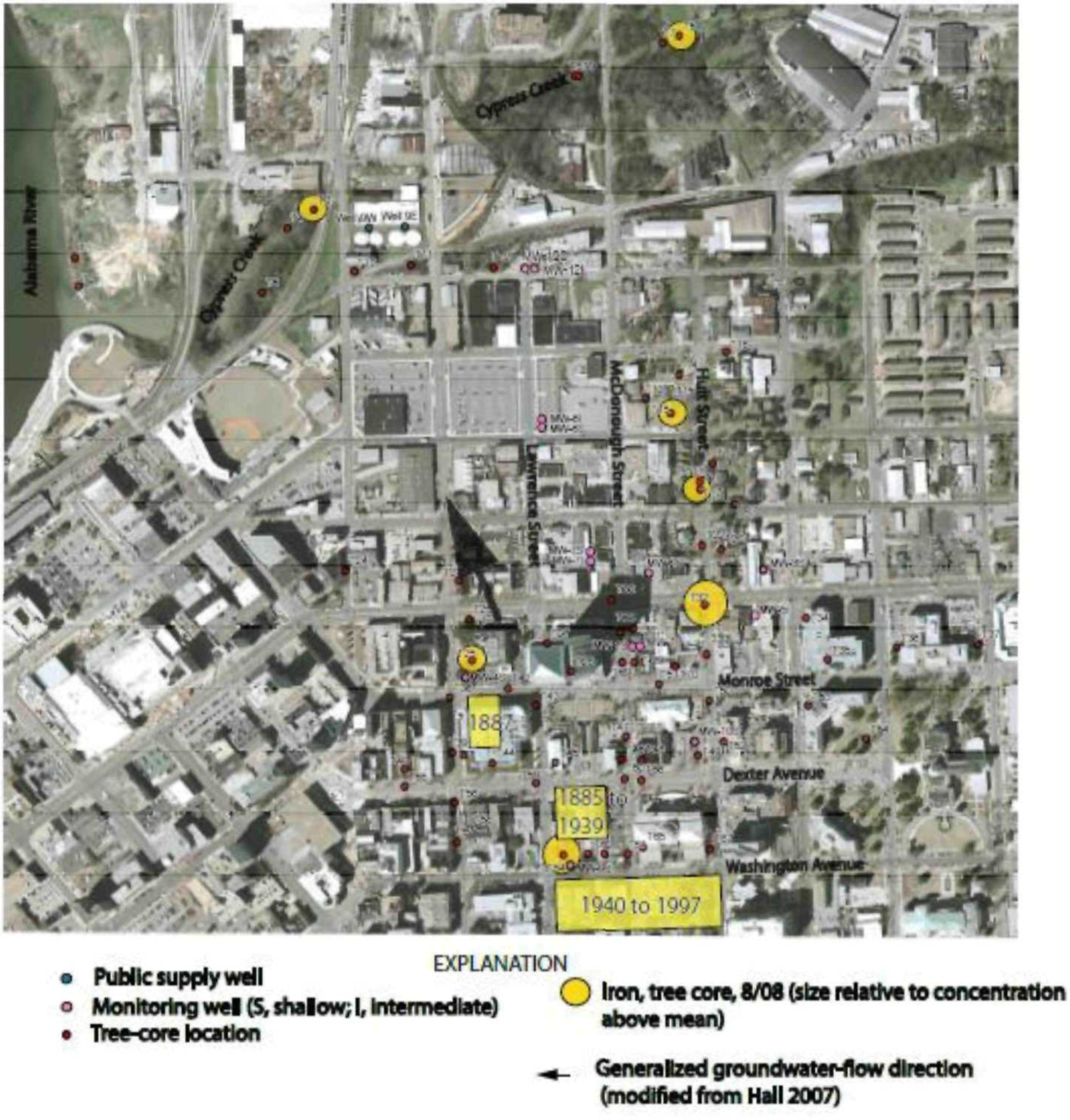


Figure 12e-. Results of PIXE analysis of iron in tree cores, August 2008. Trees are depicted that had concentrations above the mean for all trees.

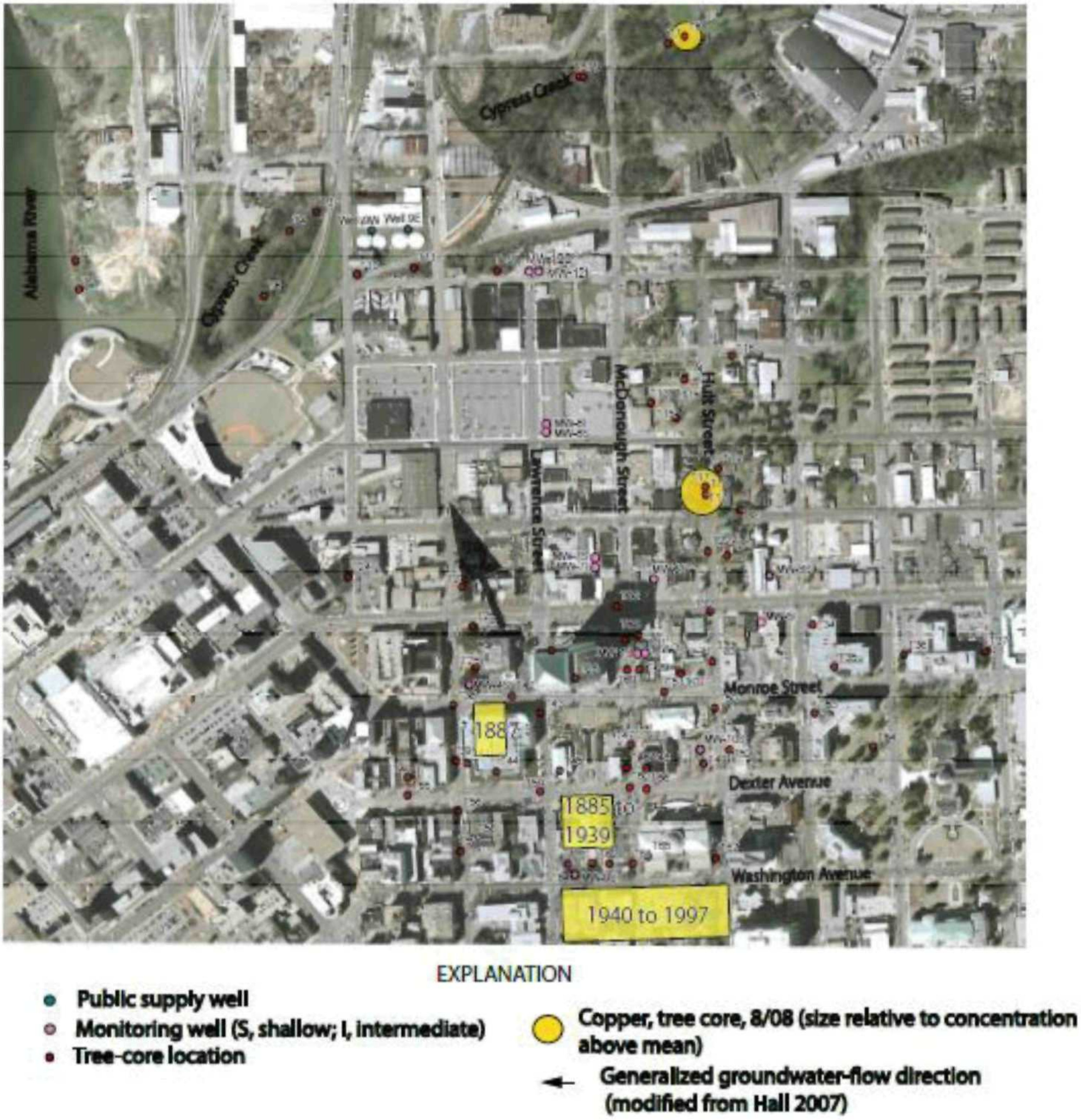


Figure 12f-. Results of PIXE analysis of copper in tree cores, August 2008. Trees are depicted that had concentrations above the mean for all trees.

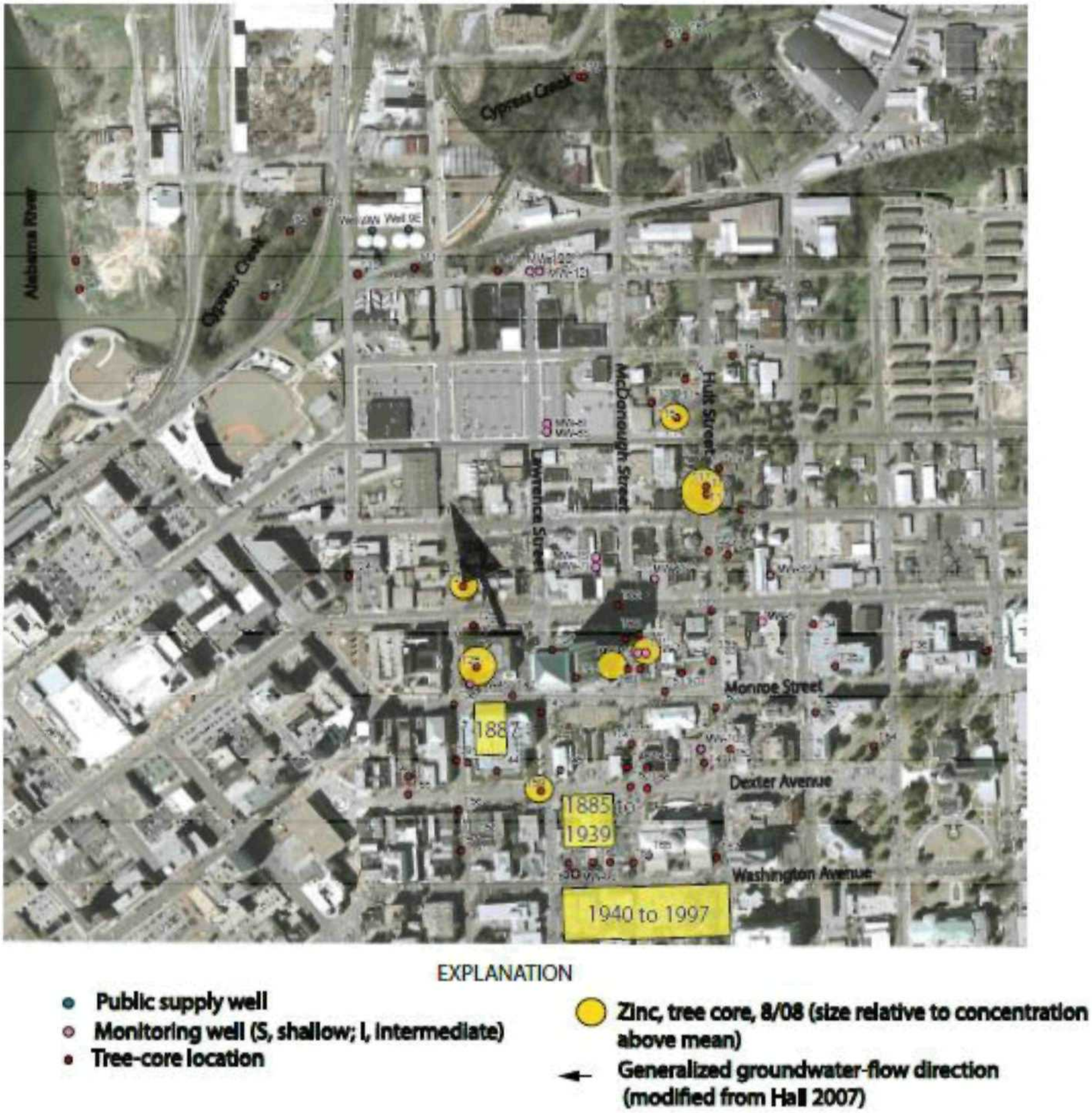


Figure 12g-. Results of PIXE analysis of zinc in tree cores, August 2008. Trees are depicted that had concentrations above the mean for all trees.

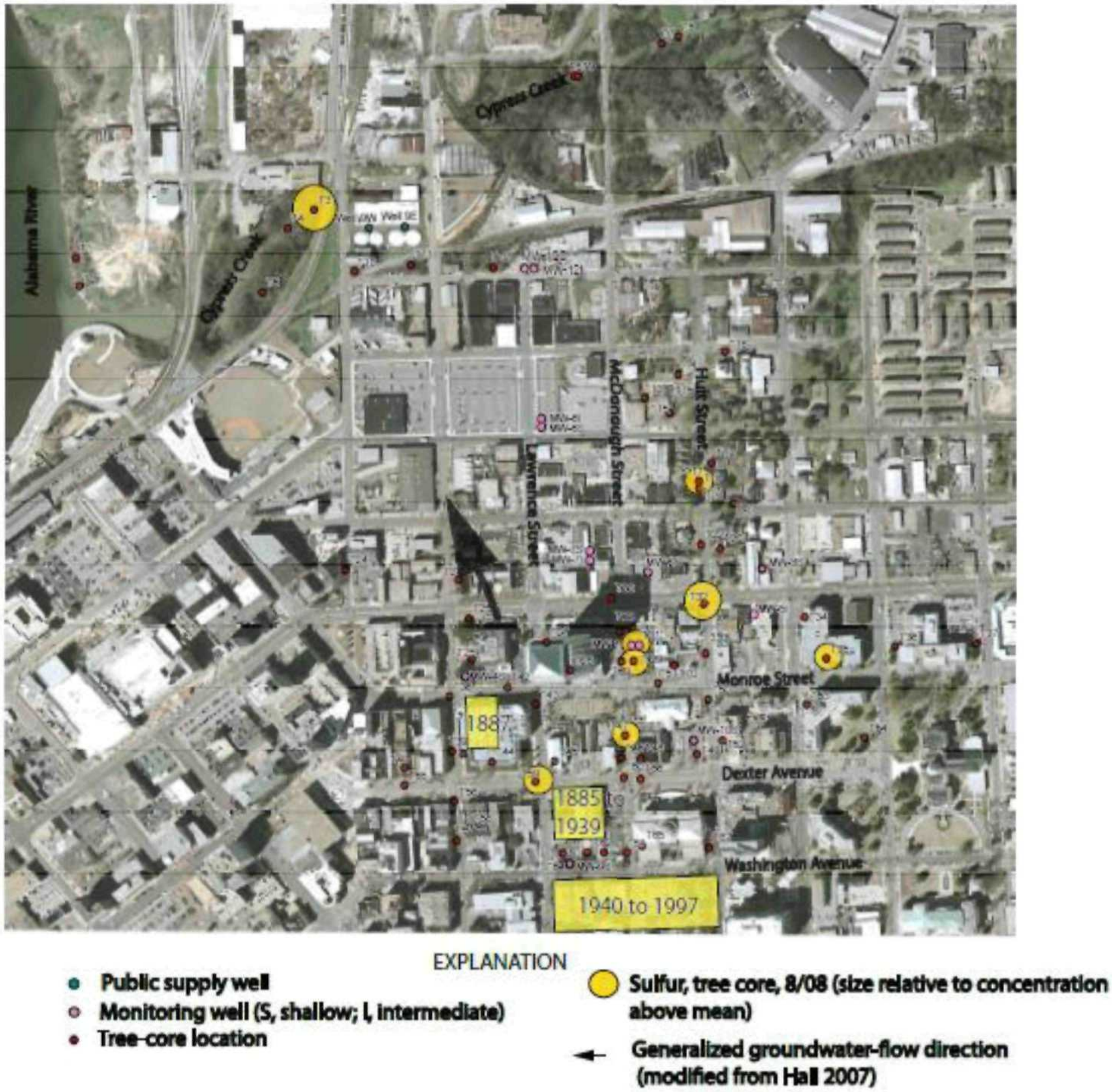


Figure 12h-. Results of PIXE analysis of sulfur in tree cores, August 2008. Trees are depicted that had concentrations above the mean for all trees.

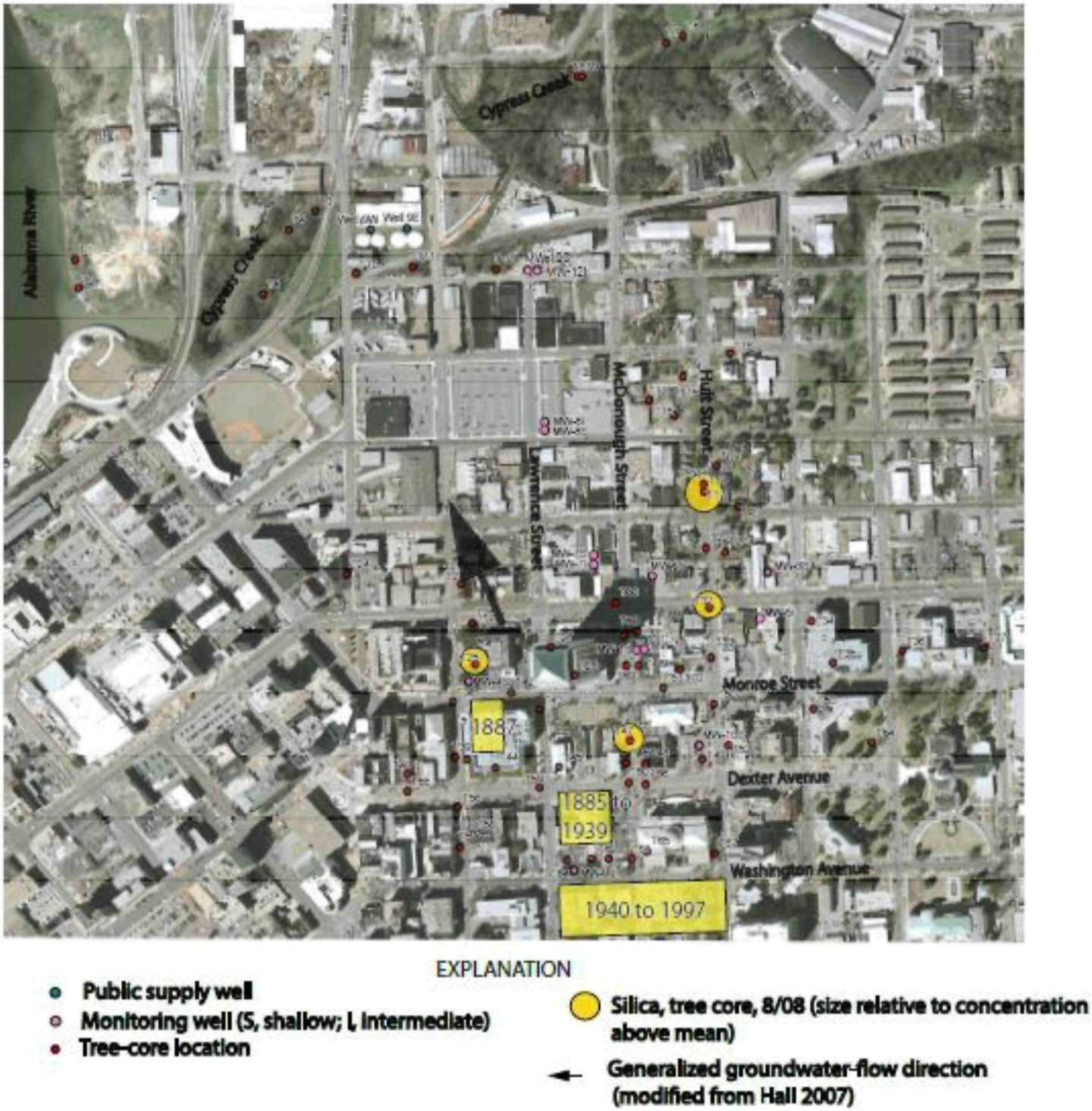


Figure 12i-. Results of PIXE analysis of silica in tree cores, August 2008. Trees are depicted that had concentrations above the mean for all trees.

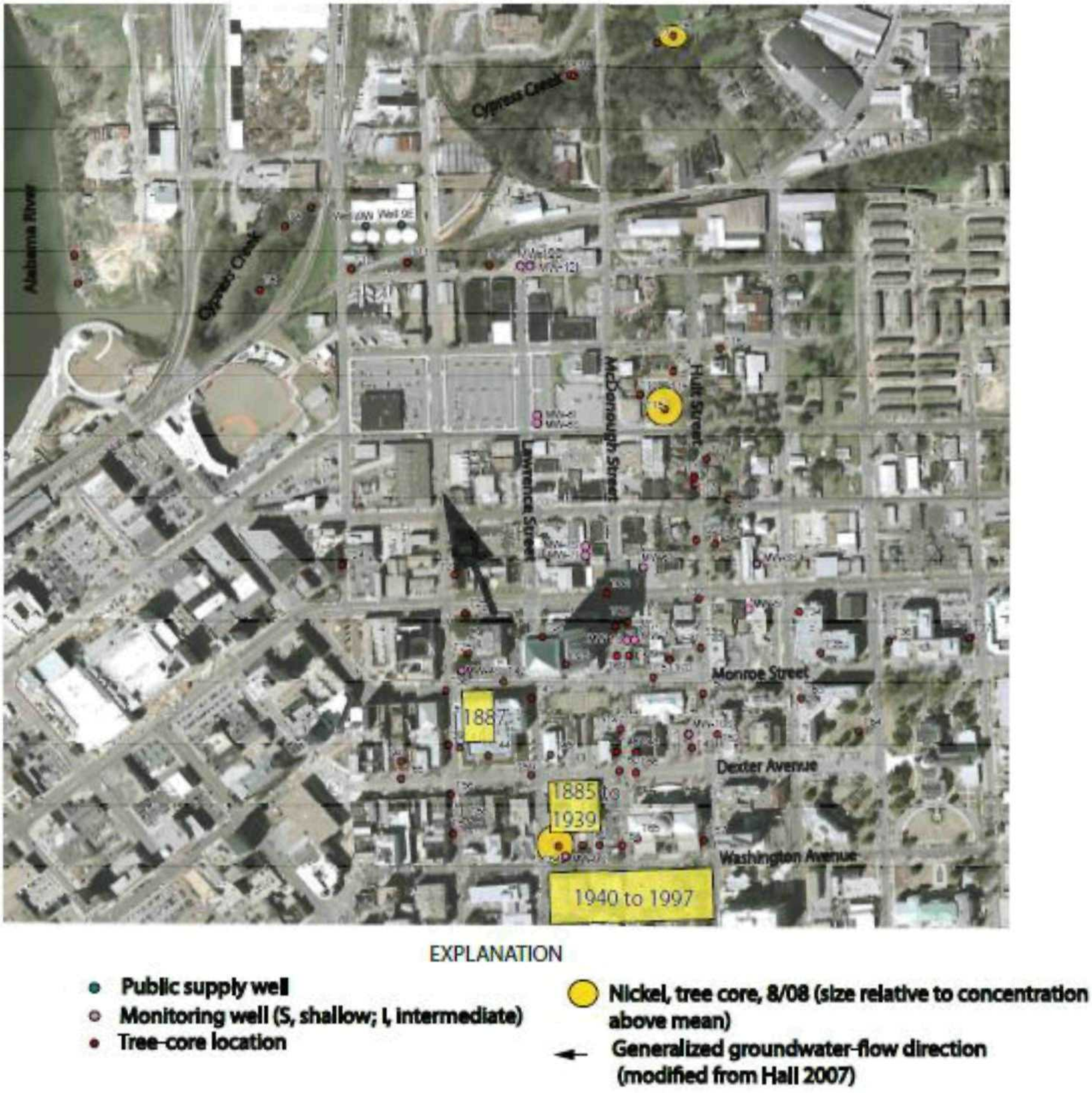


Figure 12j-. Results of PIXE analysis of nickel in tree cores, August 2008. Trees are depicted that had concentrations above the mean for all trees.

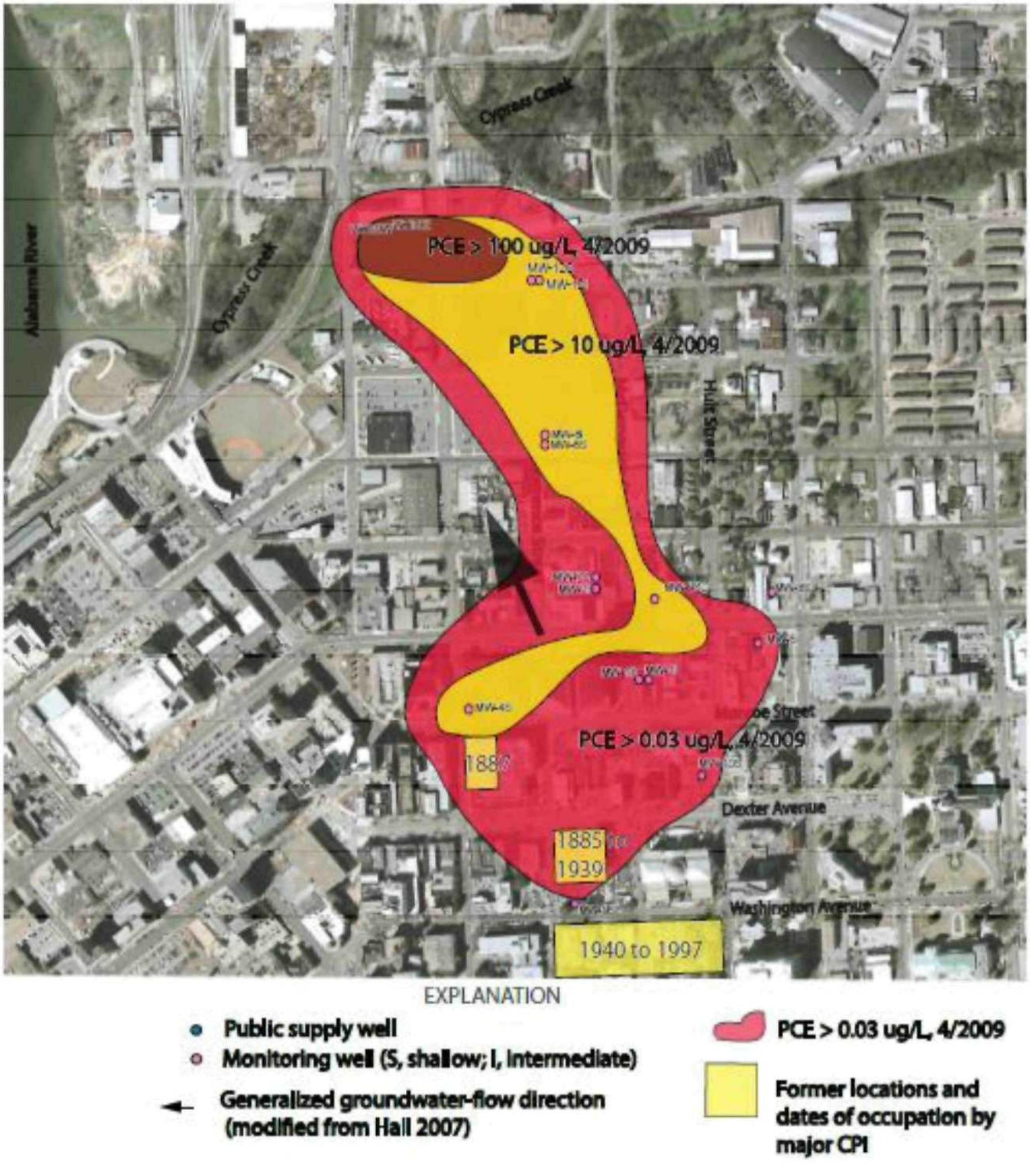


Figure 13a. Locations of PCE in groundwater, data from USGS sampling April–May 2009, with former locations and dates occupied by a major commercial printing industry. PCE data for 9W from MWWSSB.

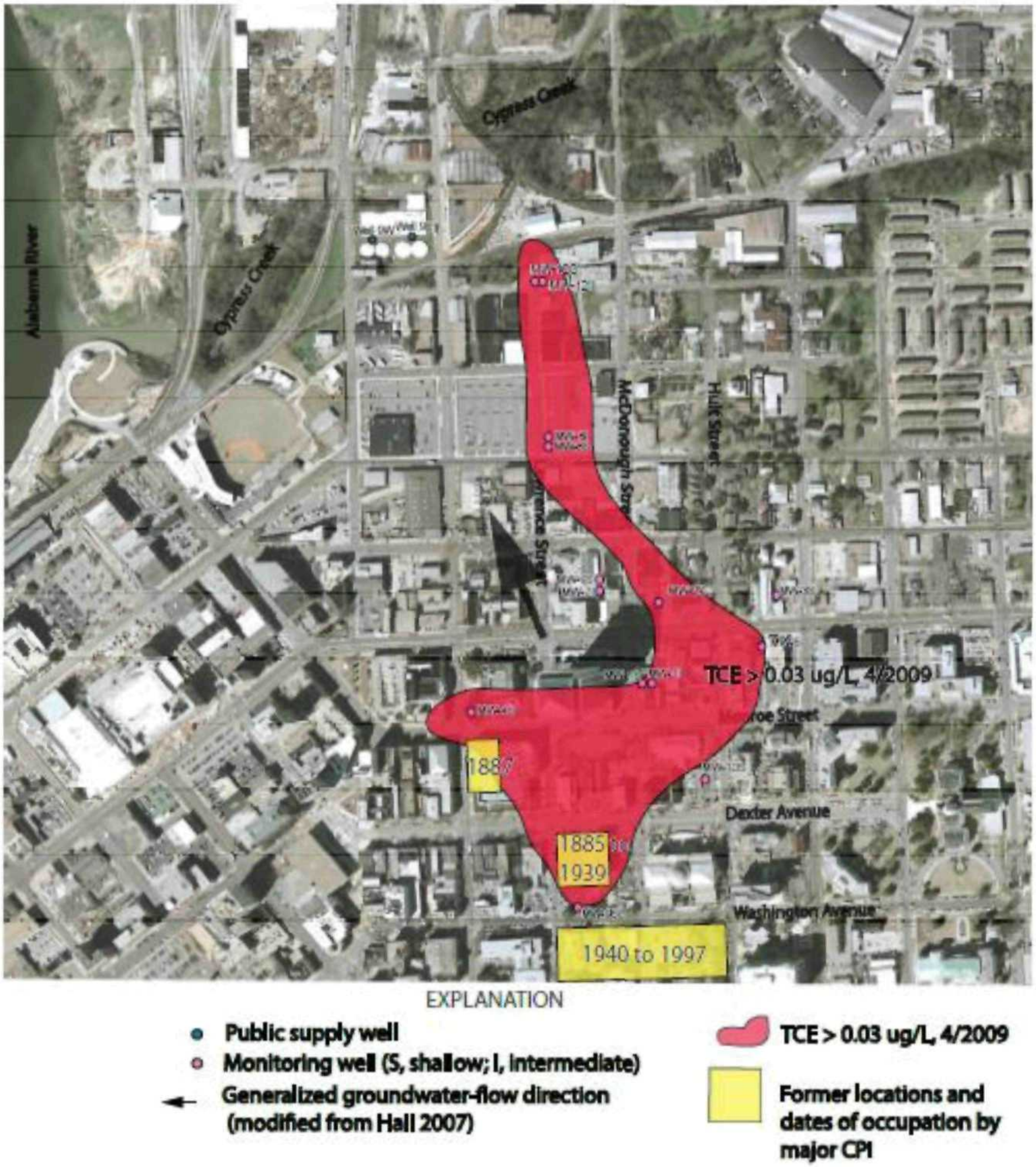


Figure 13b. Locations of TCE in groundwater, data from USGS sampling April–-May 2009, with former locations and dates occupied by a major commercial printing industry. TCE data for 9W from MWWSSB.

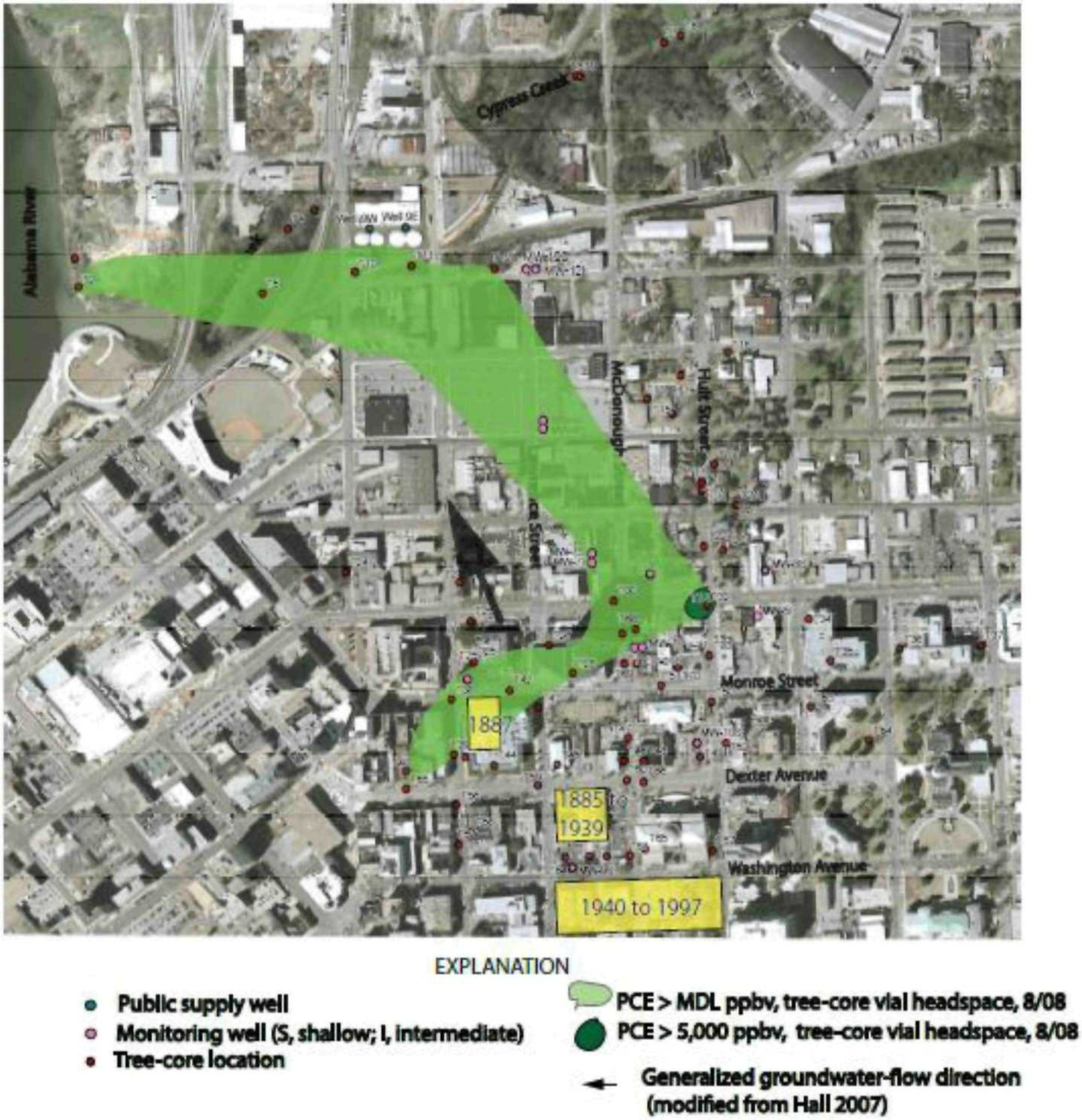


Figure 14a. Locations of PCE in tree-core vial headspace, ppbv, data from USGS sampling August 2008, with former locations and dates occupied by a major commercial printing industry.

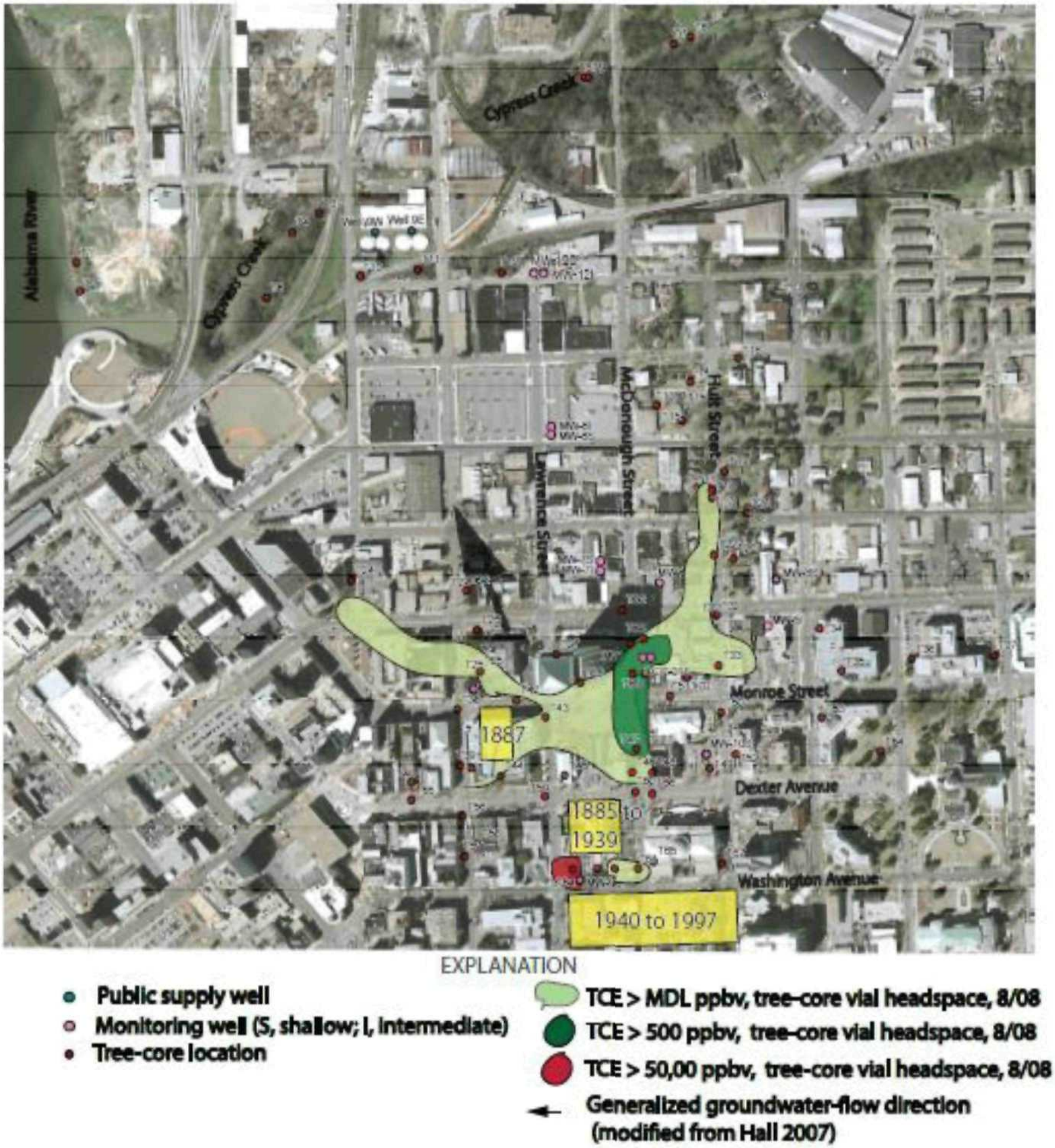


Figure 14b. Locations of TCE in tree-core vial headspace, ppbv, data from USGS sampling August 2008, with former locations and dates occupied by a major commercial printing industry.

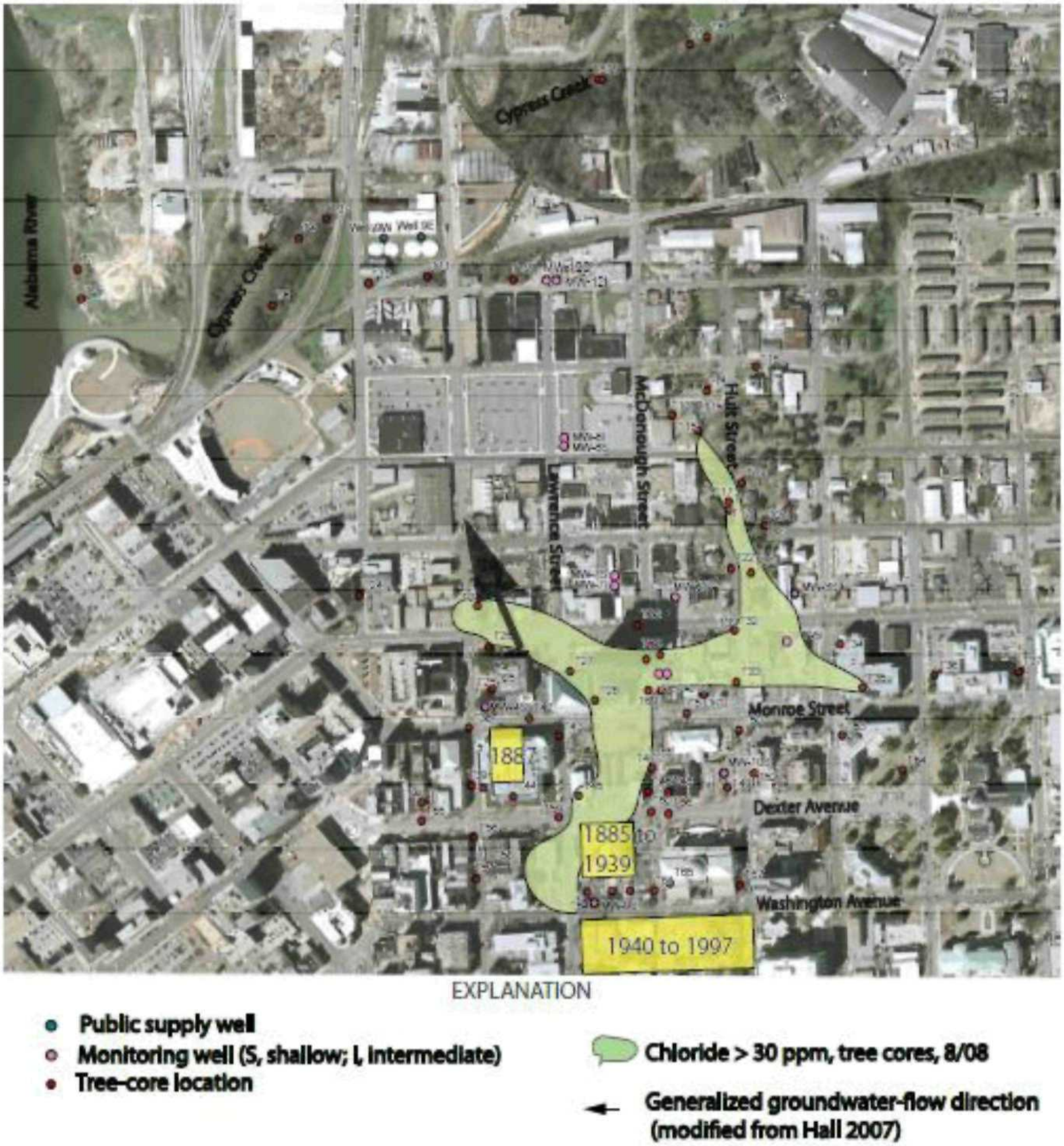


Figure 14c. Locations of chloride greater than 30 ppmin tree cores data from USGS sampling August 2008.

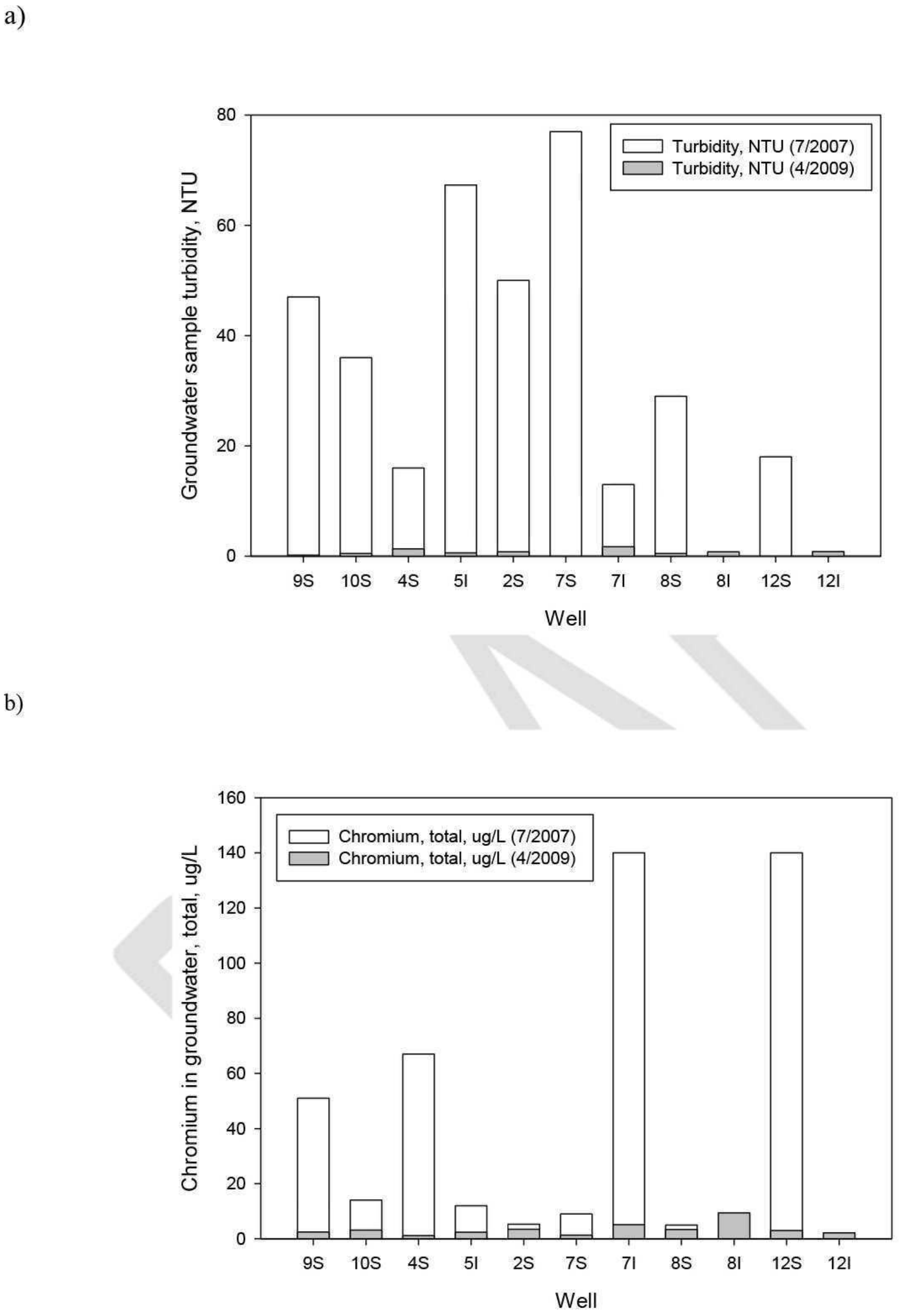


Figure 15. Comparison of groundwater sample (a) turbidity and (b) total chromium for sampling events on July 2007 and April–May 2009.

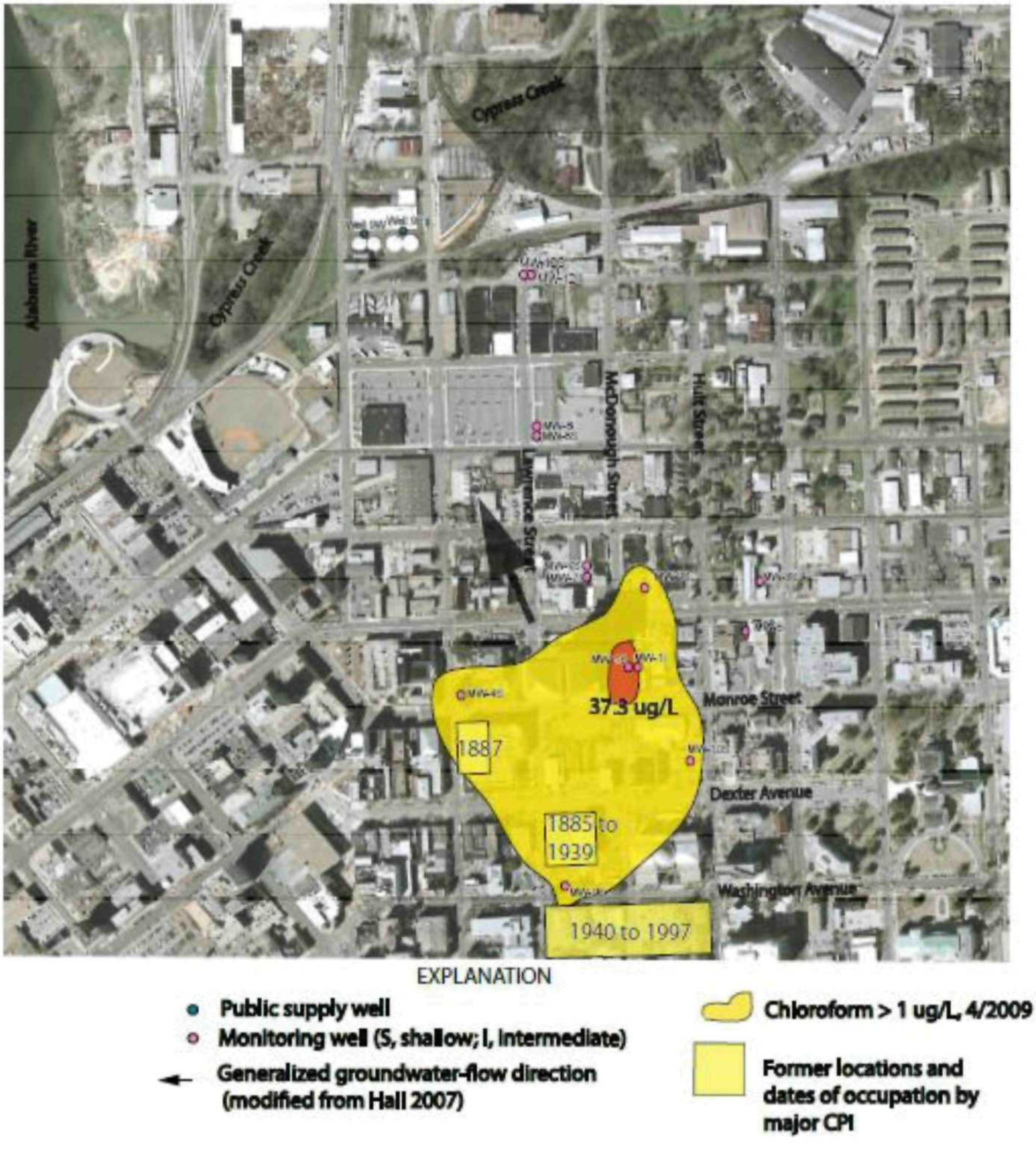


Figure 16. Monitoring wells with chloroform plume April–May 2009.

Figure 17. Location of sanitary sewer system, slopes from outfalls, and flow direction.

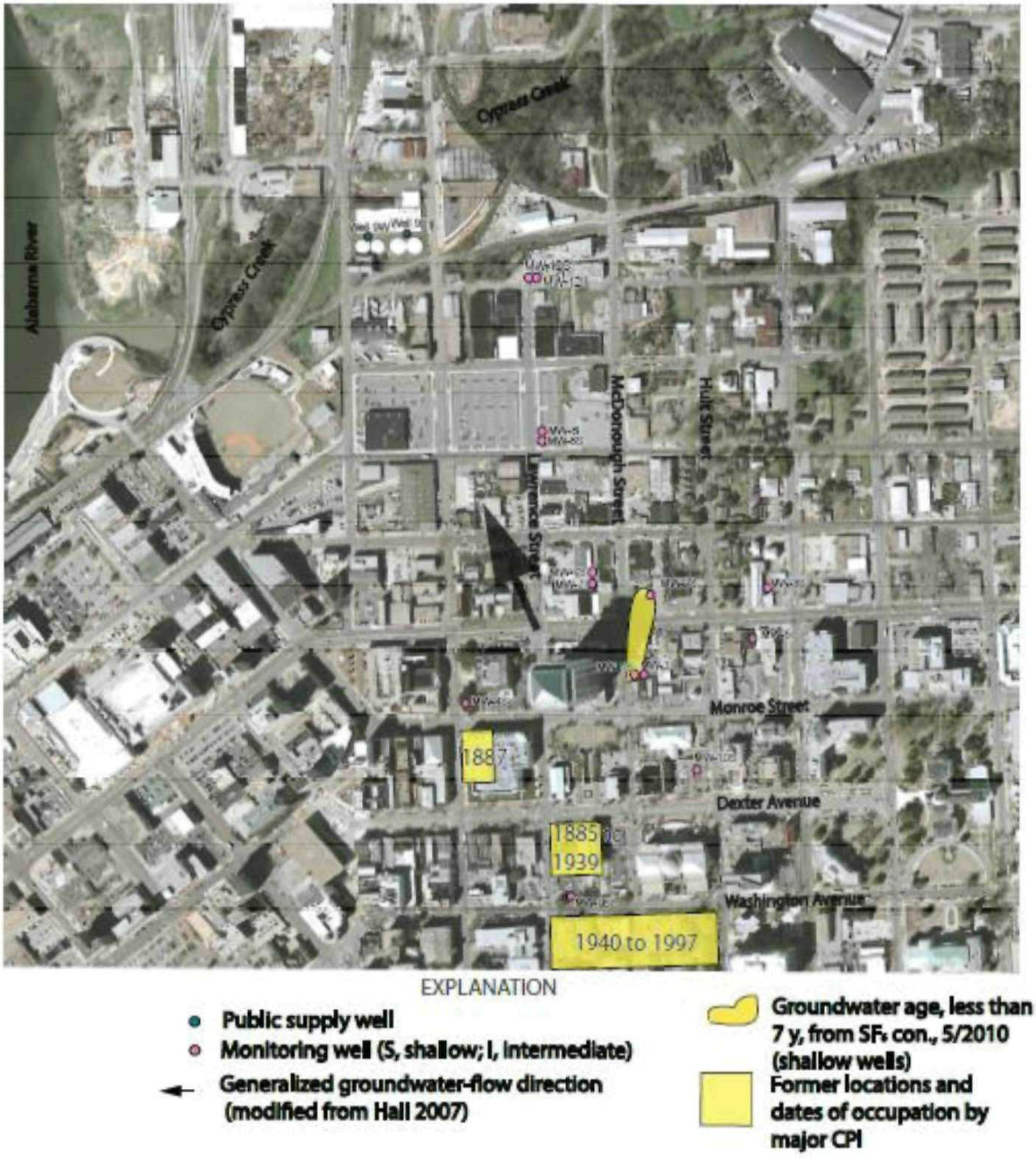


Figure 18a. Shallow MWs with groundwater age from SF_6, May Jume 2010.

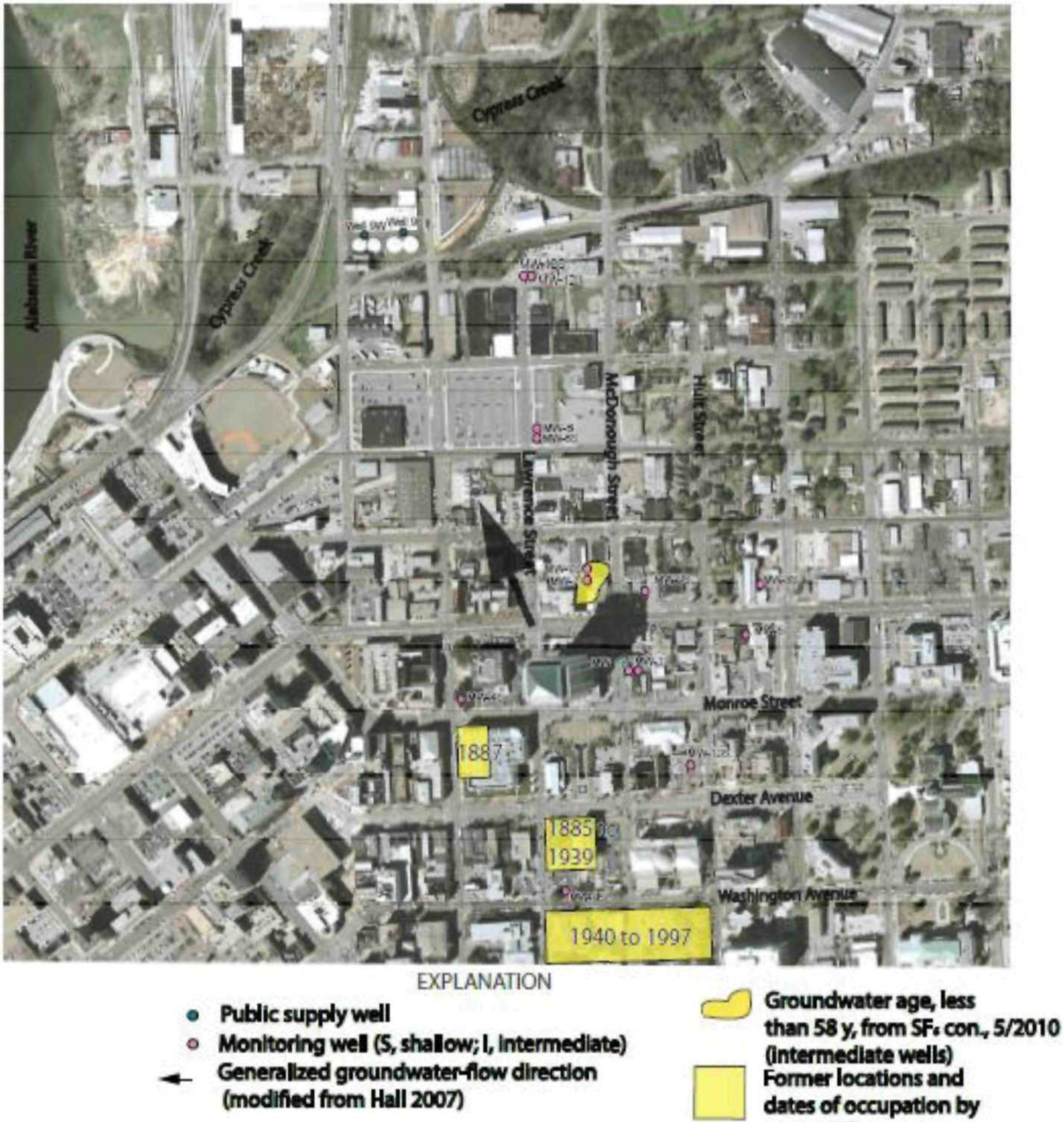


Figure 18b. Intermediate MWs with groundwater age from SF_6, May Jume 2010.

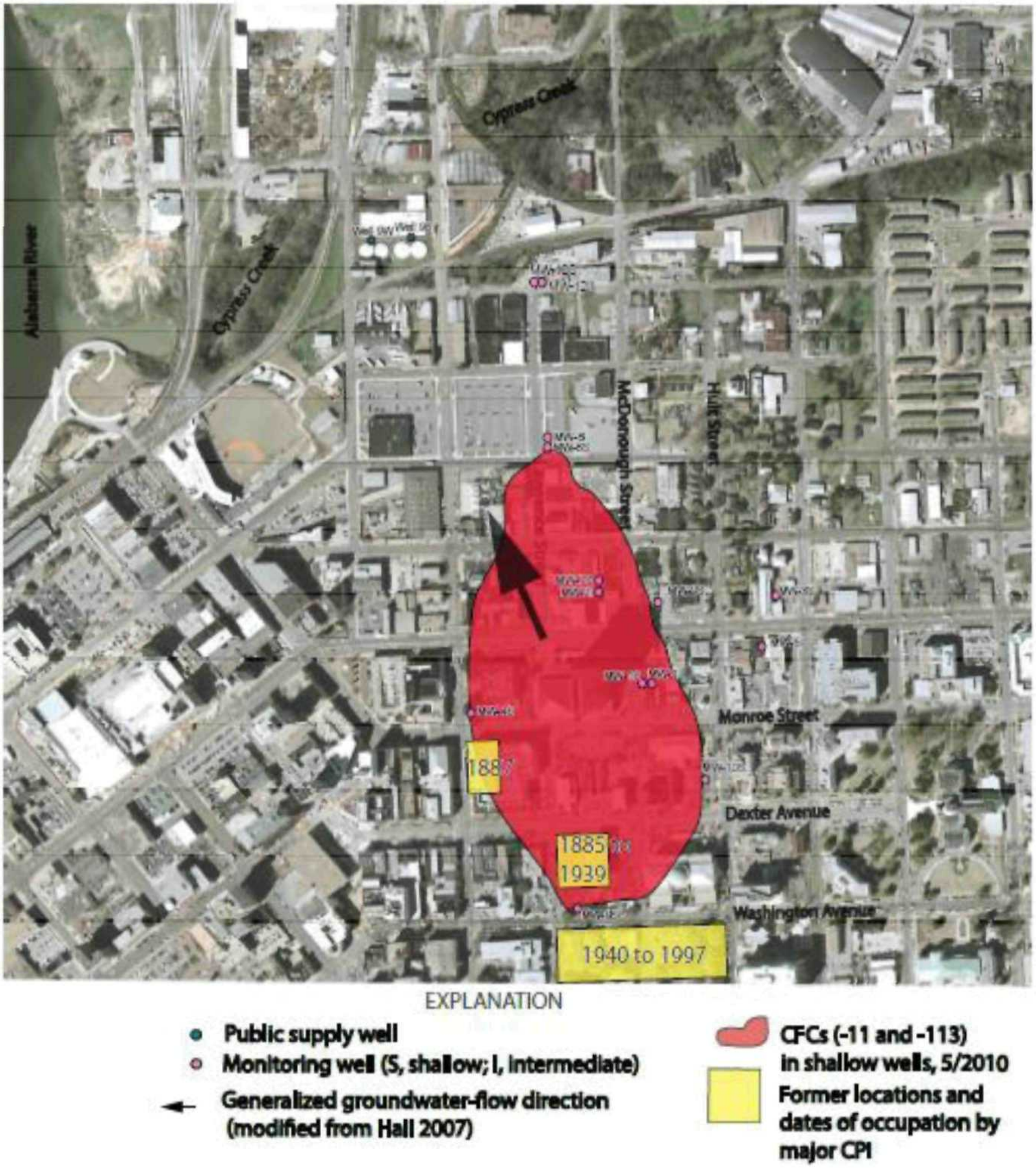


Figure 19a. Shallow MWs with CFC concentrations, May 2010.

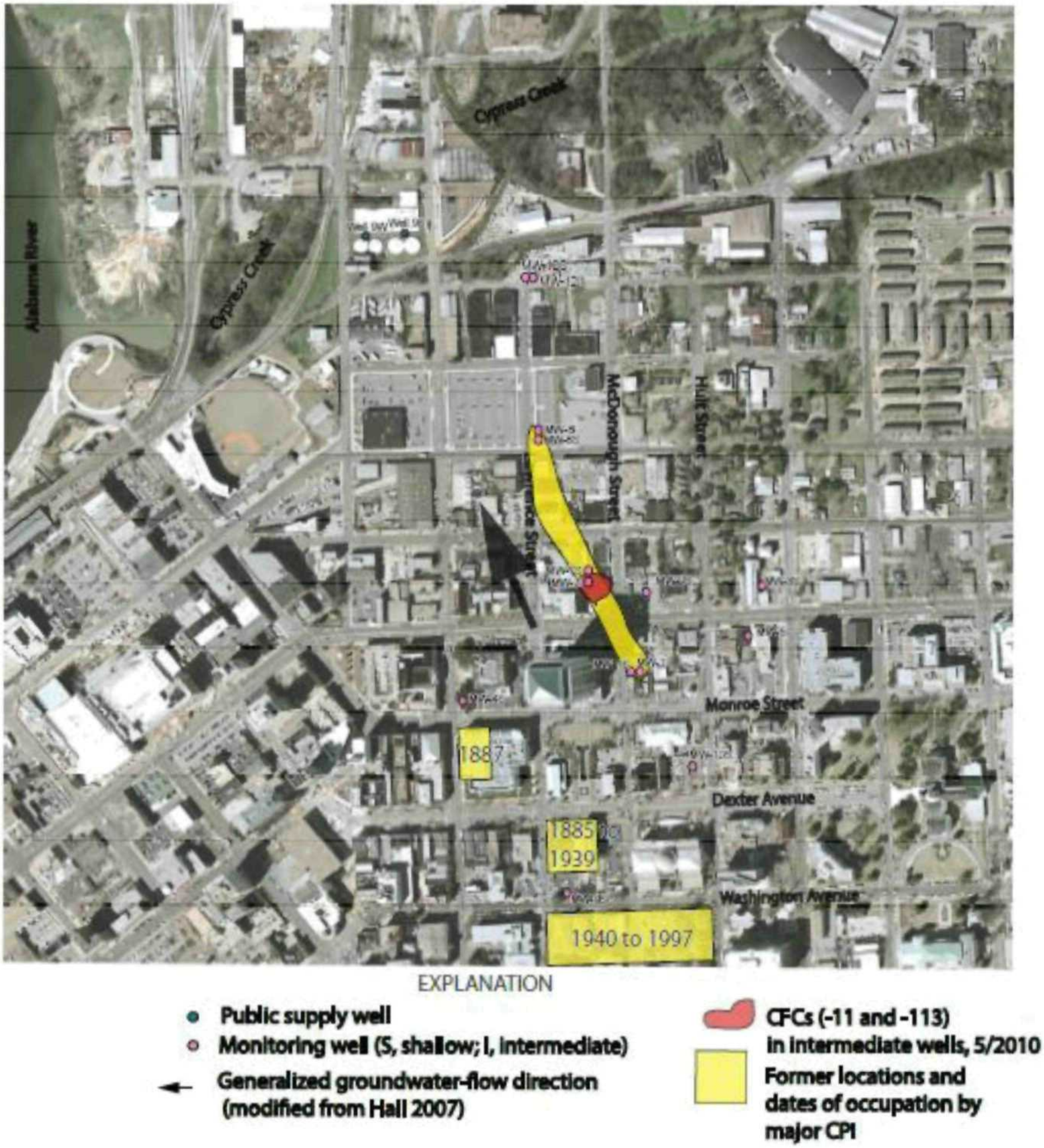


Figure 19b. Intermediate MWs with CFC concentration, May 2010.

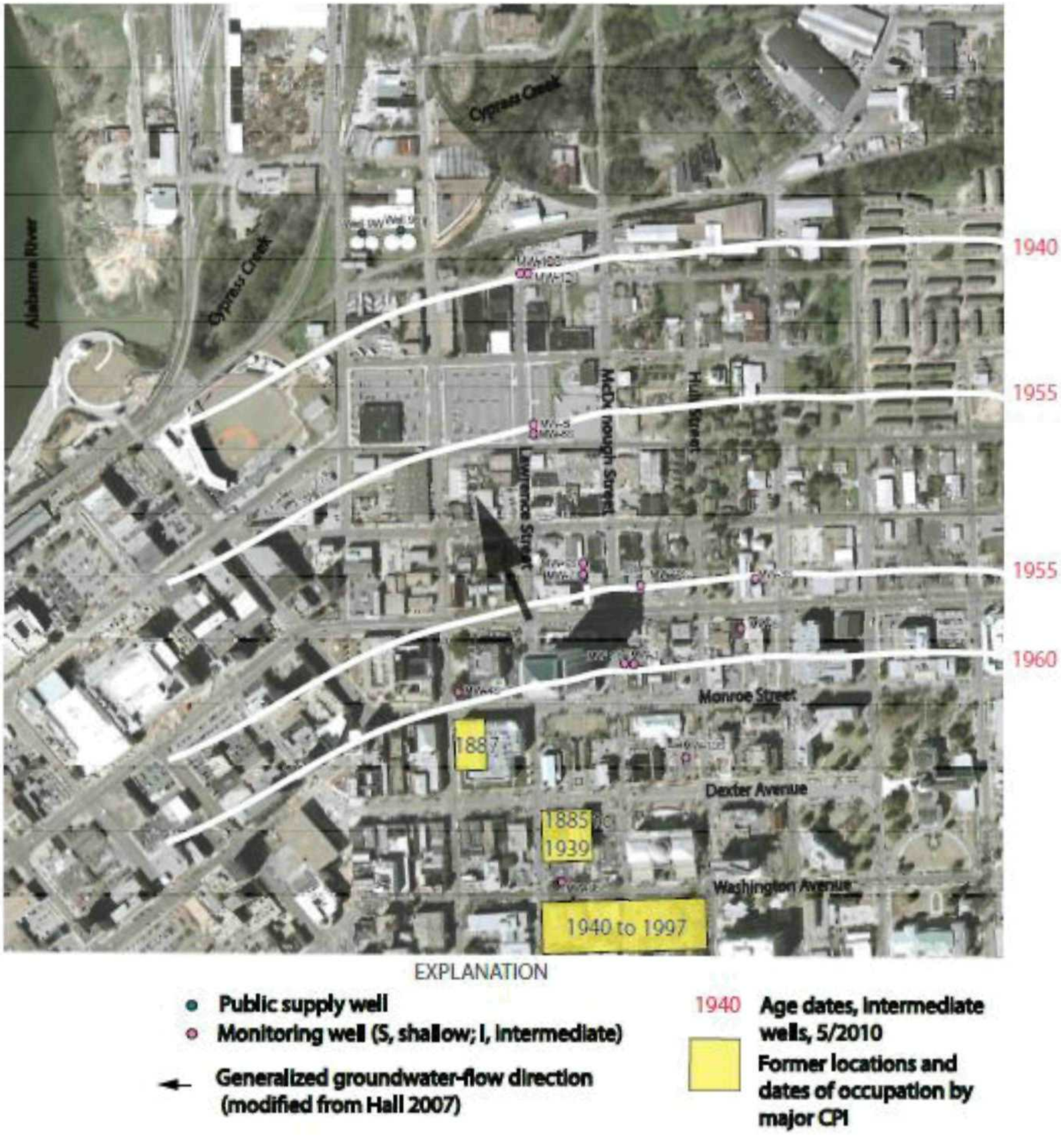


Figure 20. CFC-based recharge age, May 2010.

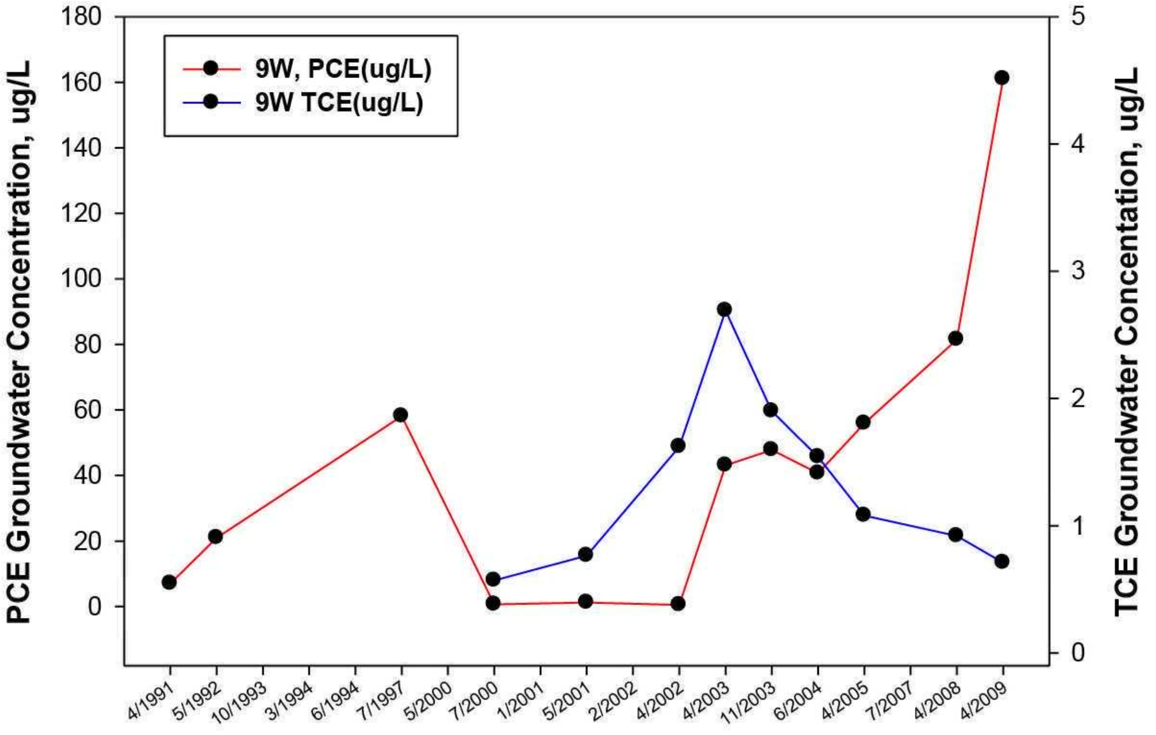


Figure 21 . Trends for PCE and TCE in well 9W since 1991.

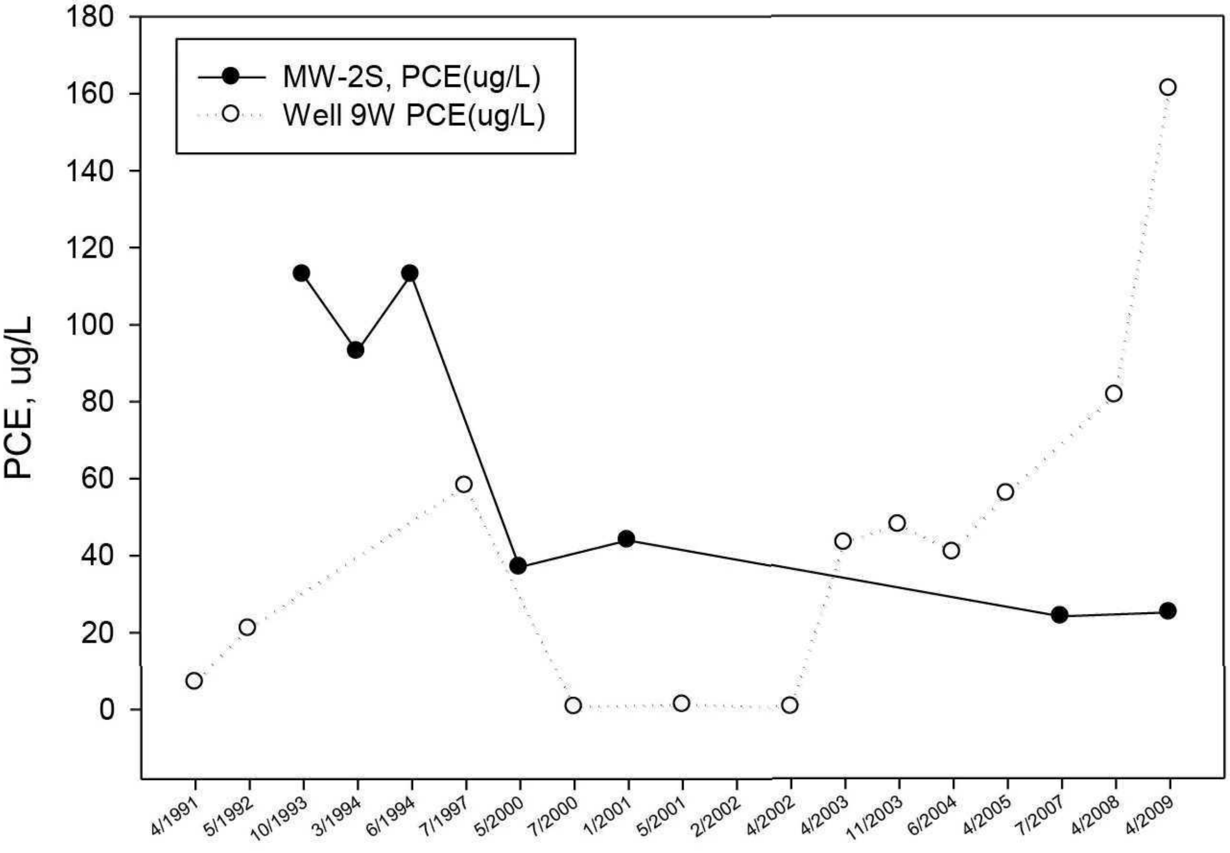


Figure 22a. Trends for PCE in MW-2S and 9W over time. PCE has decreased in MW-2S since 1993, and a roughly equal increase of PCE has been observed in downgradient and nonpuming well 9W.

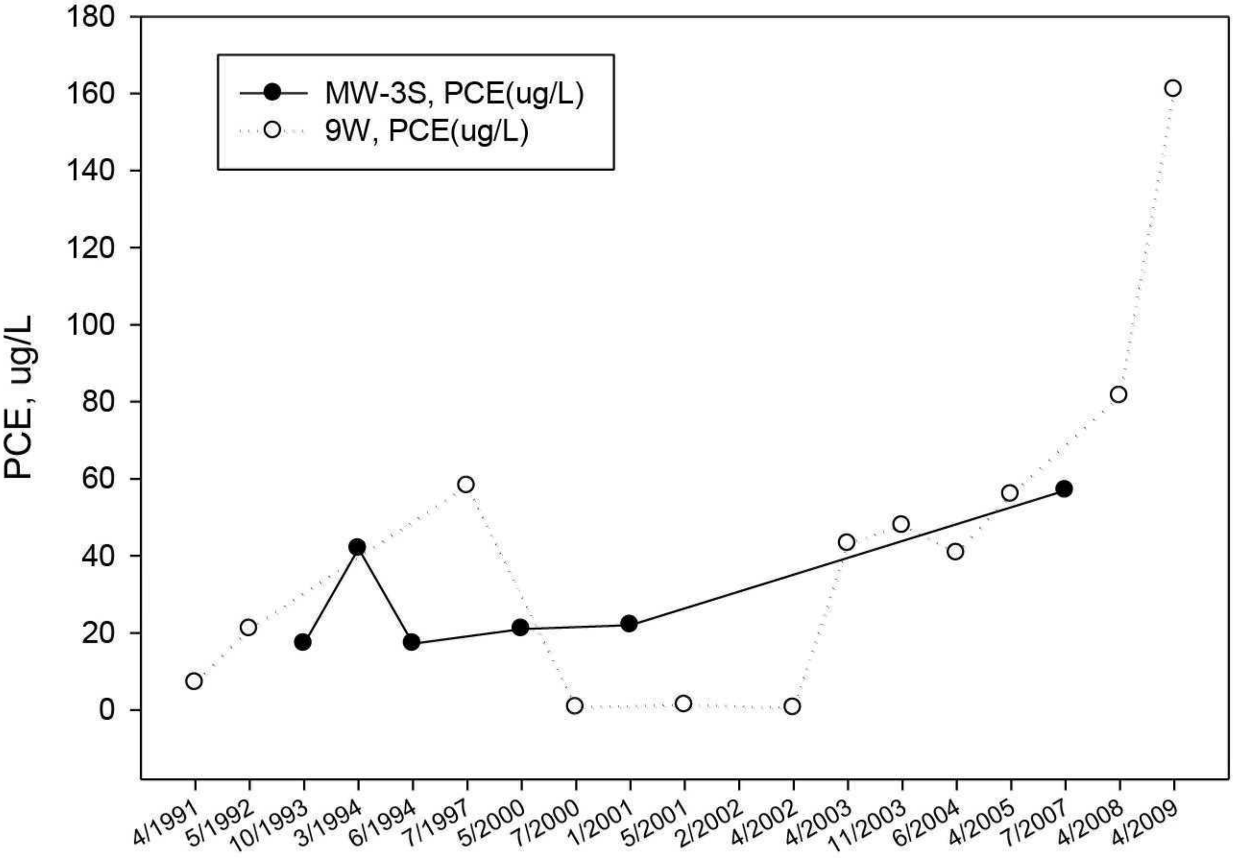


Figure 22b. Trends for PCE in MW-3S and 9W over time. PCE in 9W decreased as PCE in well MW-3S slightly increased. Since 2003, PCE has increased in both wells, although to a greater extent in 9W.

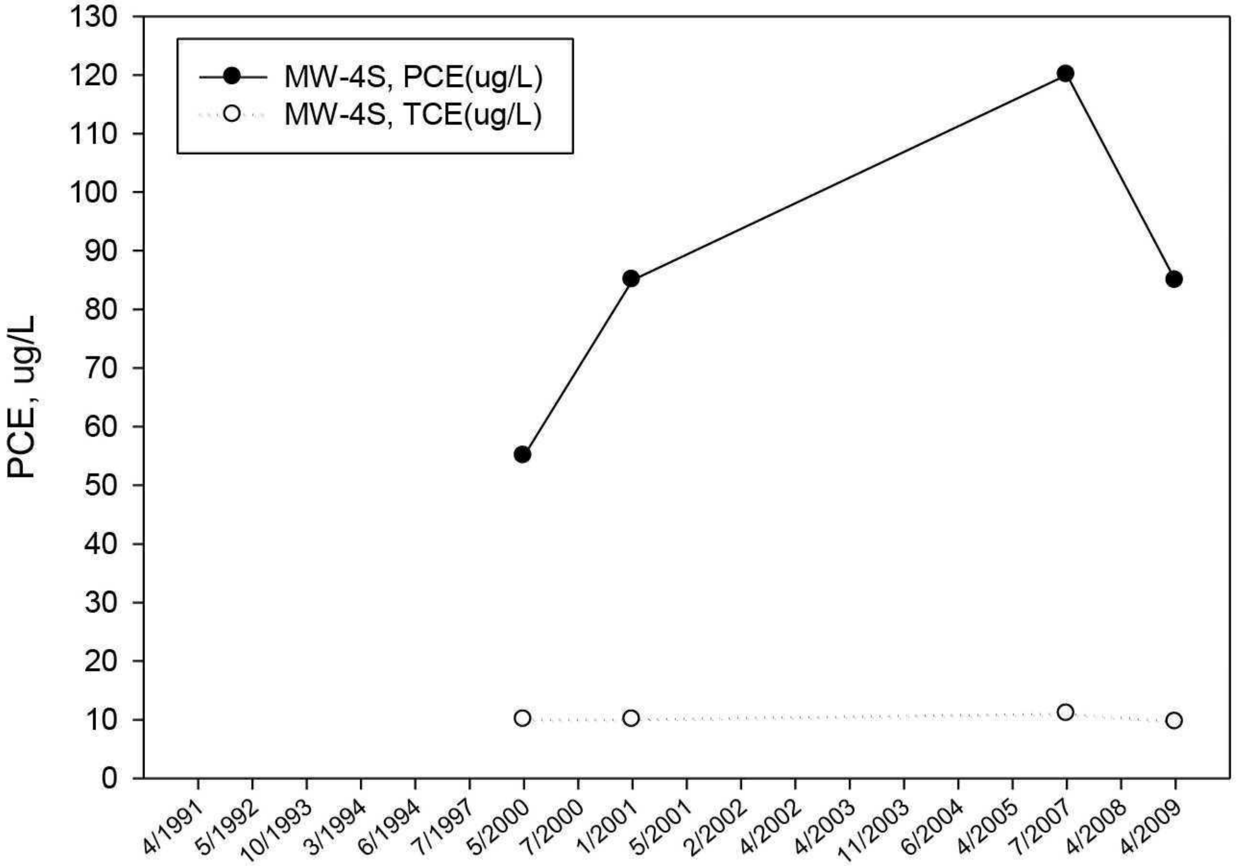


Figure 22c. Trends for PCE and TCE in well MW-4S since 1997

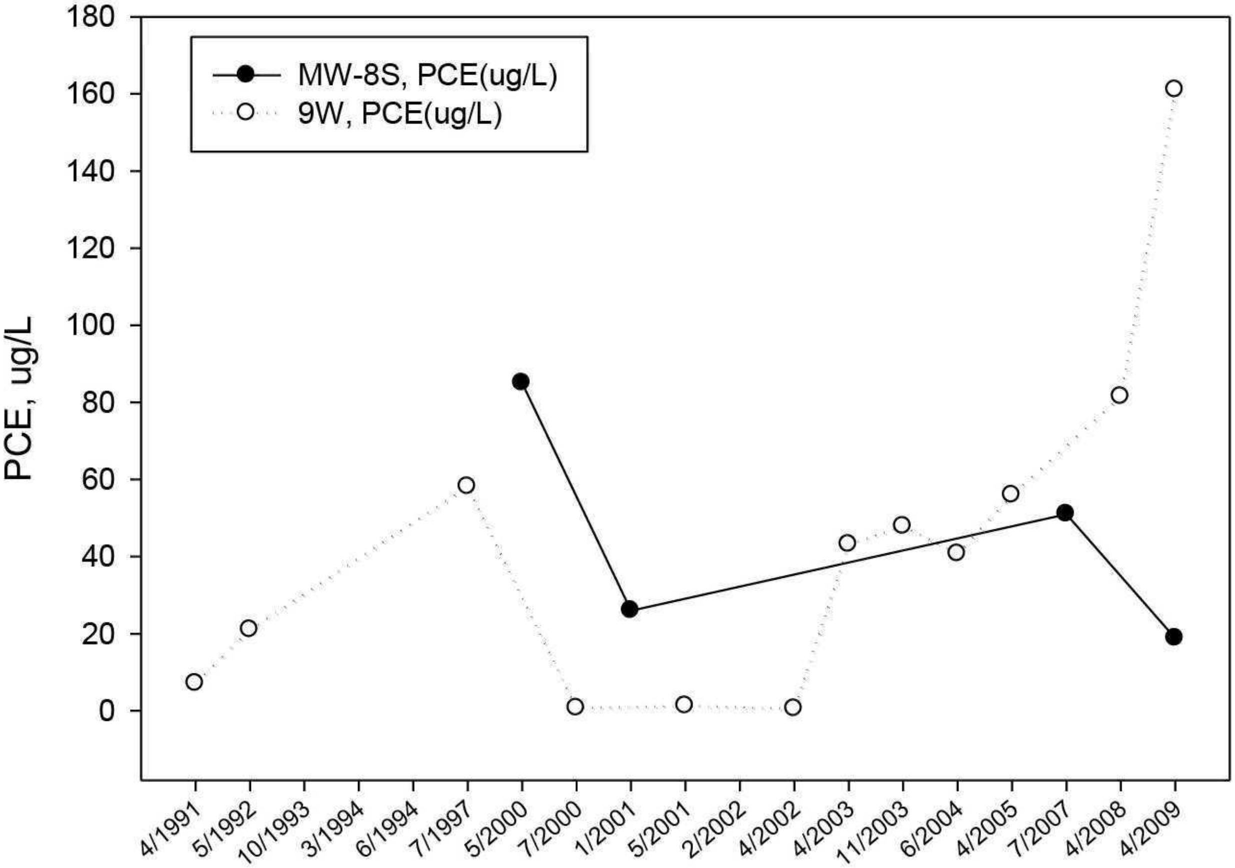


Figure 22d. Trends for PCE in well MW-8S since 1991.

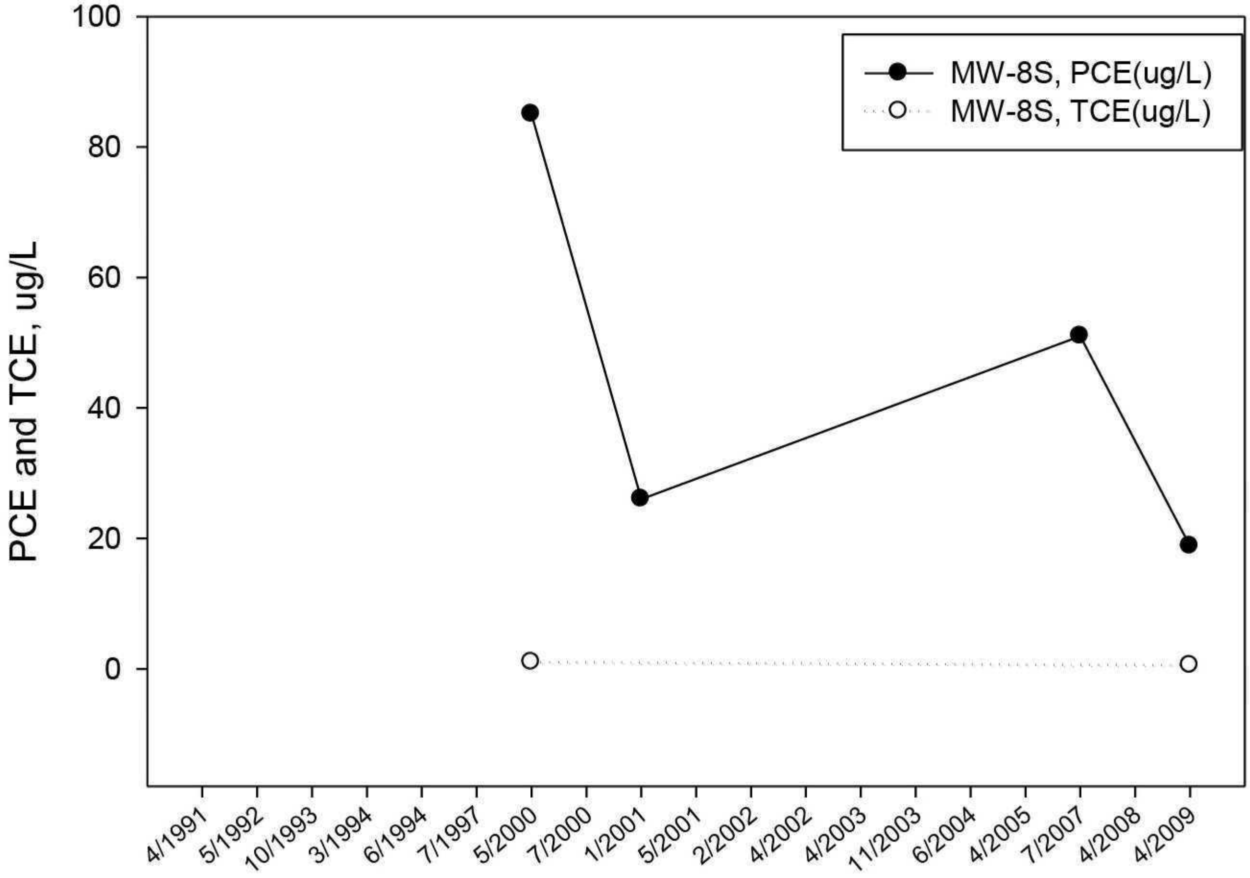


Figure 22e. Trends for PCE and TCE in well MW-8S since 1997.

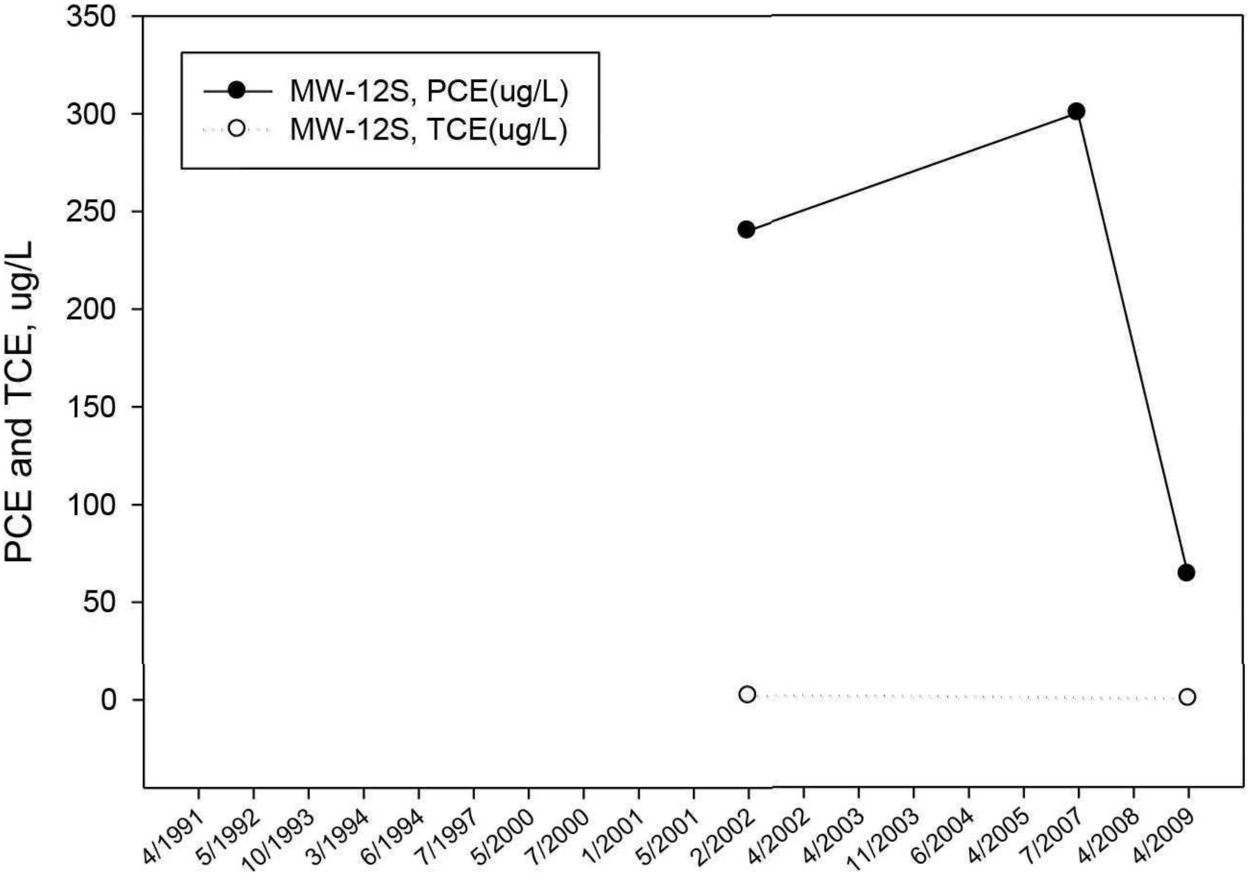


Figure 22f. Trends of PCE and TCE in well MW-12S since 2002.

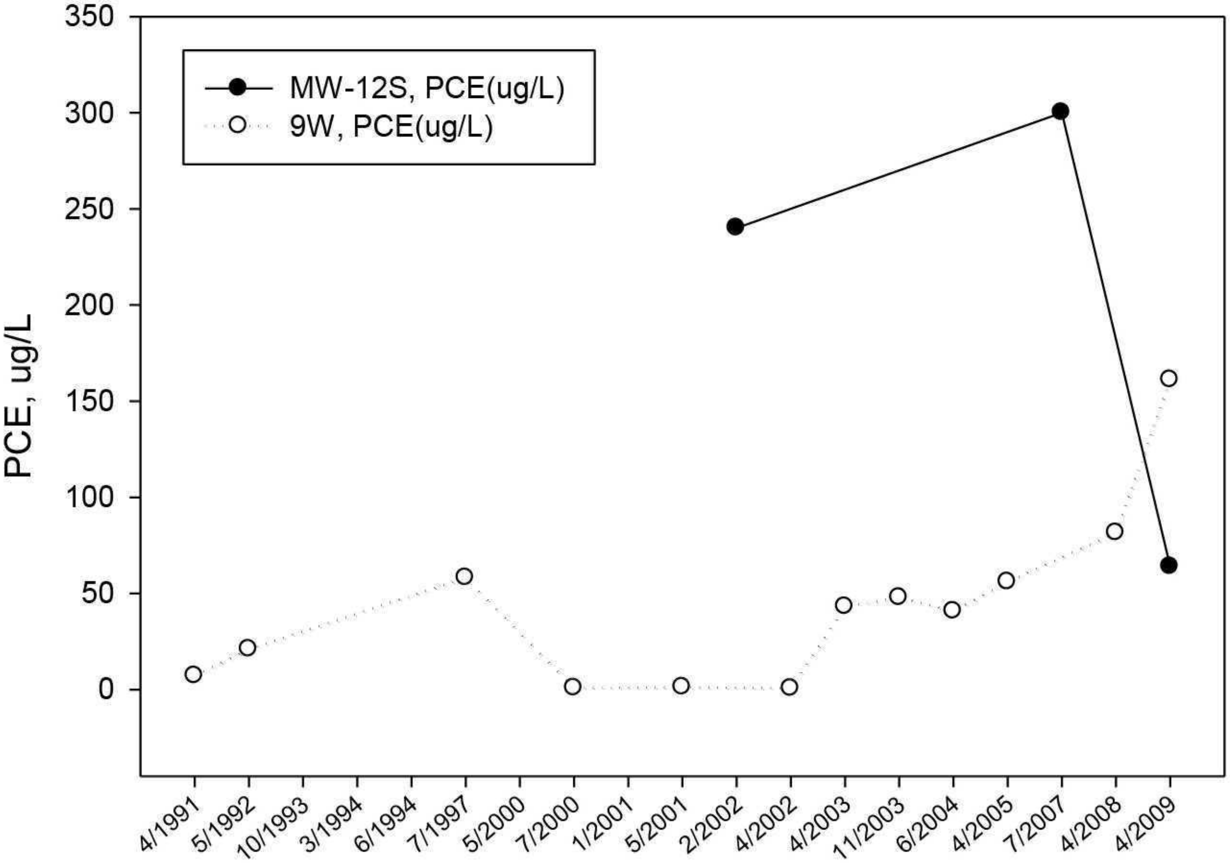


Figure 22g. Trends for PCE in MW-12S and well 9W since 1991.

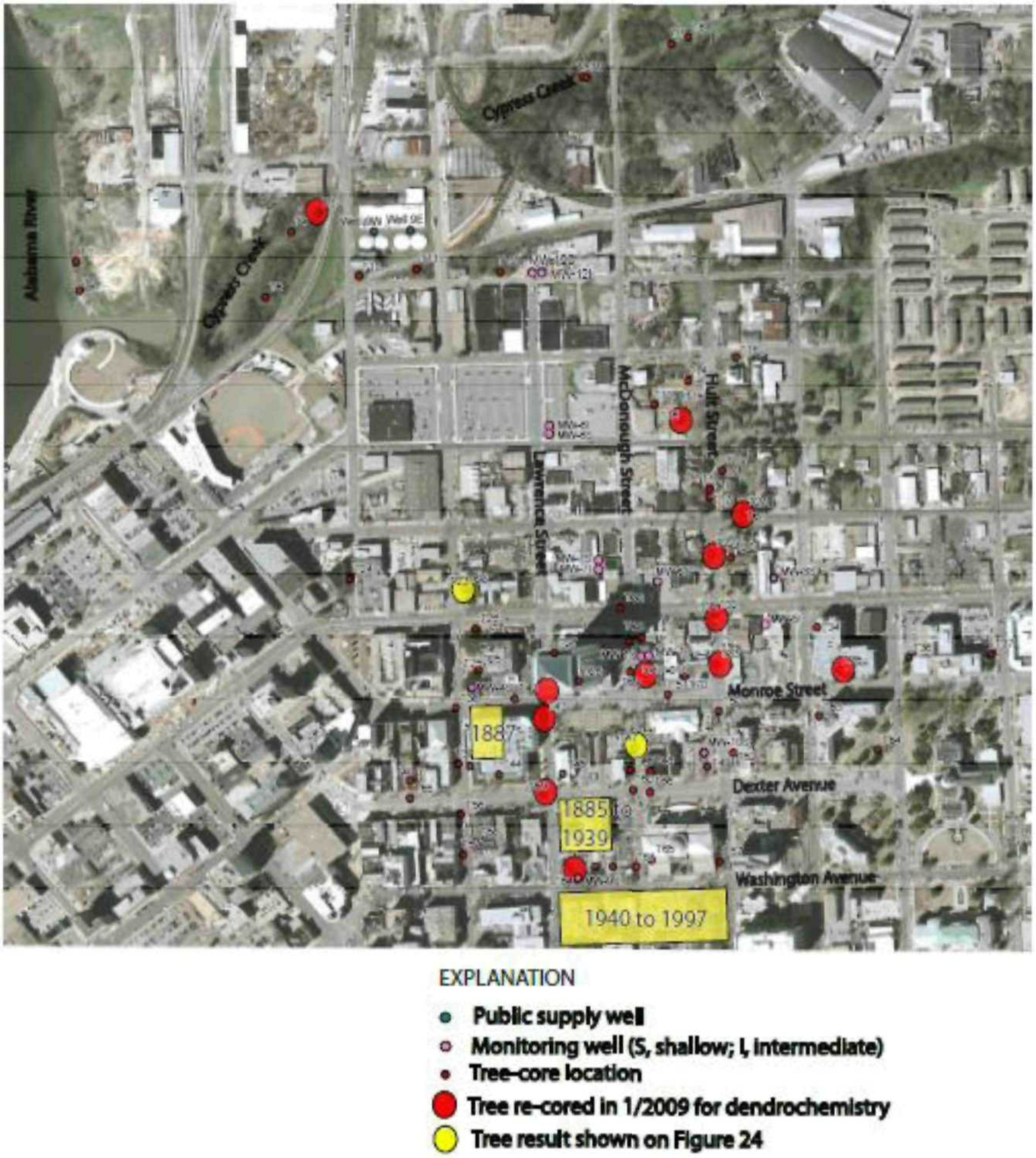
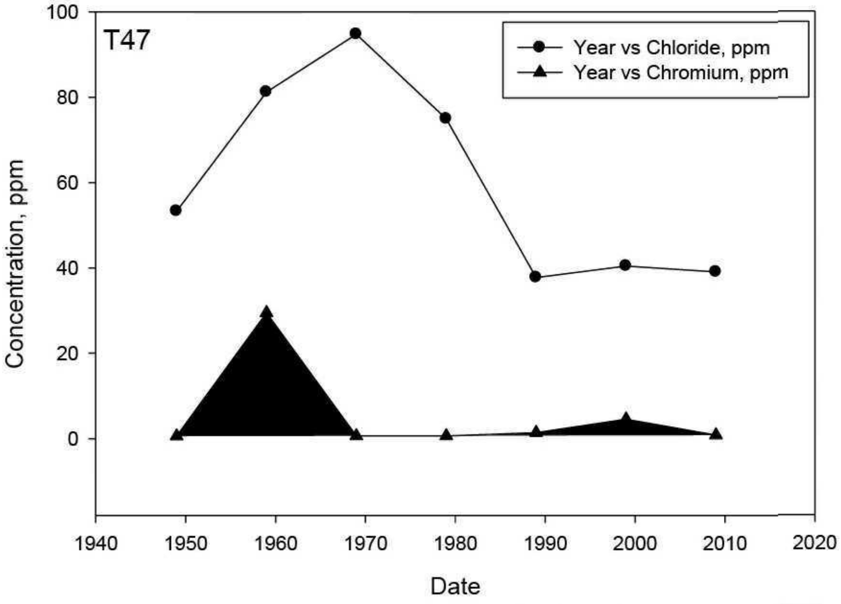


Figure 23. Location of trees cored for dendrochemistry, January 2009. Location of T23 and T47 shown.

a)



b)

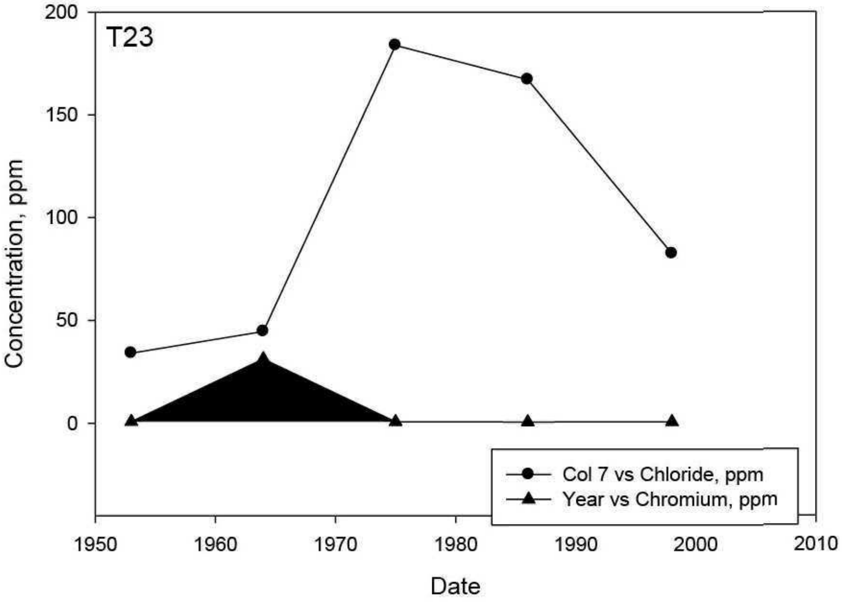


Figure 24. Peak concentrations of chloride and chromium in T47 and T23 collected January 2009.

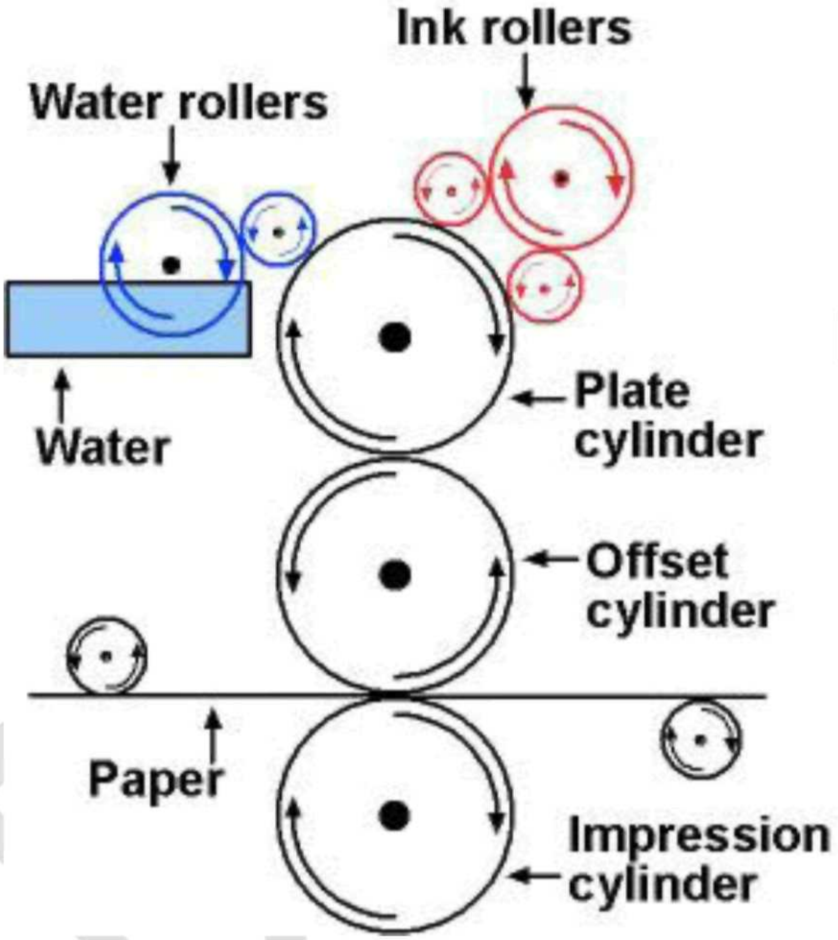


Figure 25. Offset printing process that uses blanket wash on the offset, or blanket, cylinder.

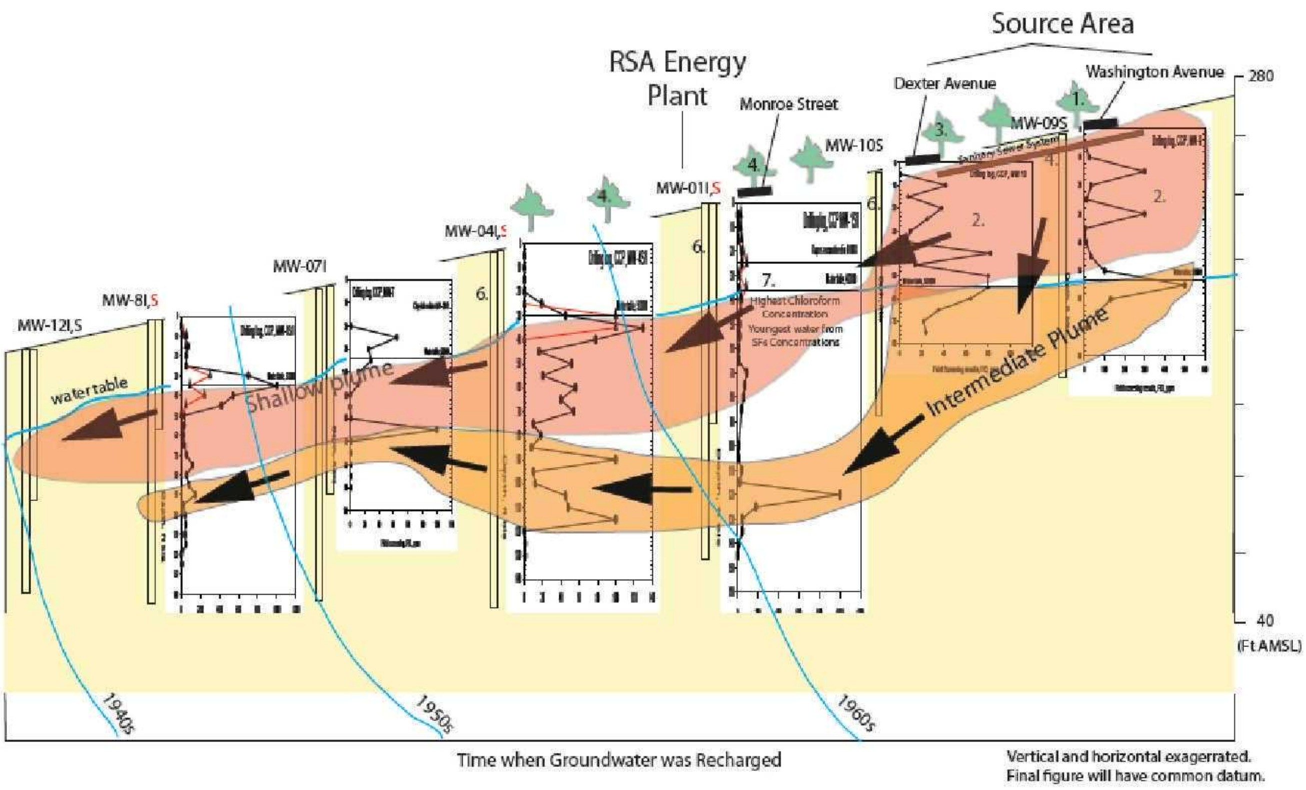


Figure 26. Presentation of the determination of the CCP Site source area, contaminant pathways, and probable release history.