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NATIONAL WATER-QUALITY ASSESSMENT PROGRAM

Comparison Between Agricultural and Urban Ground-Water Quality in the Mobile River Basin, 1999–2001

U.S. Geological Survey
Water-Resources Investigations Report 03-4182

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

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By James L. Robinson

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Montgomery, Alabama
2003

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

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

Cover photographs—*Top*: Two views of the Tallapoosa River near Milstead, Alabama. *Right*: Railroad crossing over the Tallapoosa River near Tallassee, Alabama (just upstream from Milstead), with Thurlow Dam in the background. *Bottom*: Agricultural field near Milstead, Alabama *(photographs taken by D.A. Harned, U.S. Geological Survey)*.

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FOREWORD

The U.S. Geological Survey (USGS) is committed to serve the Nation with accurate and timely scientific information that helps enhance and protect the overall quality of life, and facilitates effective management of water, biological, energy, and mineral resources. Information on the quality of the Nation's water resources is of critical interest to the USGS because it is so integrally linked to the long-term availability of water that is clean and safe for drinking and recreation and that is suitable for industry, irrigation, and habitat for fish and wildlife. Escalating population growth and increasing demands for the multiple water uses make water availability, now measured in terms of quantity *and* quality, even more critical to the long-term sustainability of our communities and ecosystems.

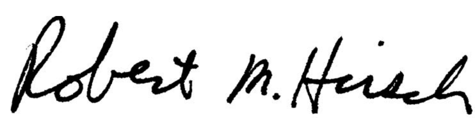
The USGS implemented the National Water-Quality Assessment (NAWQA) Program to support national, regional, and local information needs and decisions related to water-quality management and policy. Shaped by and coordinated with ongoing efforts of other Federal, State, and local agencies, the NAWQA Program is designed to answer: What is the condition of our Nation's streams and ground water? How are the conditions changing over time? How do natural features and human activities affect the quality of streams and ground water, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. NAWQA results can contribute to informed decisions that result in practical and effective water-resource management and strategies that protect and restore water quality.

Since 1991, the NAWQA Program has implemented interdisciplinary assessments in more than 50 of the Nation's most important river basins and aquifers, referred to as Study Units. Collectively, these Study Units account for more than 60 percent of the overall water use and population served by public water supply, and are representative of the Nation's major hydrologic landscapes, priority ecological resources, and agricultural, urban, and natural sources of contamination.

Each assessment is guided by a nationally consistent study design and methods of sampling and analysis. The assessments thereby build local knowledge about water-quality issues and trends in a particular stream or aquifer while providing an understanding of how and why water quality varies regionally and nationally. The consistent, multiscale approach helps to determine if certain types of water-quality issues are isolated or pervasive, and allows direct comparisons of how human activities and natural processes affect water quality and ecological health in the Nation's diverse geographic and environmental settings. Comprehensive assessments on pesticides, nutrients, volatile organic compounds, trace metals, and aquatic ecology are developed at the national scale through comparative analysis of the Study-Unit findings.

The USGS places high value on the communication and dissemination of credible, timely, and relevant science so that the most recent and available knowledge about water resources can be applied in management and policy decisions. We hope this NAWQA publication will provide you the needed insights and information to meet your needs, and thereby foster increased awareness and involvement in the protection and restoration of our Nation's waters.

The NAWQA Program recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for a fully integrated understanding of watersheds and for cost-effective management, regulation, and conservation of our Nation's water resources. The Program, therefore, depends extensively on the advice, cooperation, and information from other Federal, State, interstate, Tribal, and local agencies, non-government organizations, industry, academia, and other stakeholder groups. The assistance and suggestions of all are greatly appreciated.



Robert M. Hirsch
Associate Director for Water

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CONVERSION FACTORS, DATUMS, DEFINITIONS, and ABBREVIATIONS and ACRONYMS

Multiply	By	To obtain
	Length	
inch (in.)	2.54	centimeter
foot (ft)	0.3048	meter
mile (mi)	1.609	kilometer
	Area	
square mile (mi^2)	2.590	square kilometer
	Volume	
gallon (gal)	3.785	liter
	Flow rate	
million gallons per day (Mgal/d)	0.04381	cubic meter per second
million gallons per day per square mile [(Mgal/d)/mi^2]	1,460	cubic meter per day per square kilometer
	Hydraulic conductivity	
foot per day (ft/d)	0.3048	meter per day

Vertical and horizontal datums:

Vertical coordinate information is referenced to the North American Vertical Datum of 1988 (NAVD 88). Historical data collected and stored as National Geodetic Vertical Datum of 1929 (NGVD of 1929) have been converted to NAVD 88 for use in this publication.

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83). Historical data collected and stored as North American Datum of 1927 (NAD 27) have been converted to NAD 83 for use in this publication.

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

$$°C = (°F - 32) / 1.8$$

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).

Additional abbreviations and acronyms used in this report:

BWRA	Black Warrior River aquifer
C-18	octadecyl
CFC	chlorofluorocarbon
$CaCo_3$	calcium carbonate
CFC-11	trichlorofluoromethane ($CFCl_3$)
CFC-12	dichlorodifluoromethane (CF_2Cl_2)
CFC-113	trichlorotrifluoroethane ($C_2F_3Cl_3$)
CO_2	carbon dioxide
CO_3	carbonate ion
ECD	electron capture device
HCO_3	bicarbonate ion
in/mo	inch per month
LRL	laboratory reporting level
LTMDL	long-term method detection level
MCL	U.S. Environmental Protection Agency drinking-water maximum contaminant level
MDL	method detection level
NAWQA	National Water-Quality Assessment
NWQL	National Water Quality Laboratory
QA/QC	quality assurance and quality control
RSD	USEPA risk-specific dose health advisory for drinking water
SF_6	sulfur hexafluoride
SPE	solid-phase extraction
USEPA	U.S. Environmental Protection Agency
USGS	U.S. Geological Survey
UV	ultraviolet

Comparison Between Agricultural and Urban Ground-Water Quality in the Mobile River Basin, 1999–2001

By James L. Robinson

ABSTRACT

The Black Warrior River aquifer is a major source of public water supply in the Mobile River Basin. The aquifer outcrop trends northwest-southeast across Mississippi and Alabama. A relatively thin shallow aquifer overlies and recharges the Black Warrior River aquifer in the flood plains and terraces of the Alabama, Coosa, Black Warrior, and Tallapoosa Rivers. Ground water in the shallow aquifer and the Black Warrior River aquifer is susceptible to contamination due to the effects of land use. Ground-water quality in the shallow aquifer and the shallow subcrop of the Black Warrior River aquifer, underlying an agricultural and an urban area, is described and compared.

The agricultural and urban areas are located in central Alabama in Autauga, Elmore, Lowndes, Macon, Montgomery, and Tuscaloosa Counties. Row cropping in the Mobile River Basin is concentrated within the flood plains of major rivers and their tributaries, and has been practiced in some of the fields for nearly 100 years. Major crops are cotton, corn, and beans. Crop rotation and no-till planting are practiced, and a variety of crops are grown on about one-third of the farms. Row cropping is interspersed with pasture and forested areas. In 1997, the average farm size in the agricultural area ranged from 196 to 524 acres. The urban area is located in eastern Montgomery, Alabama, where residential and commercial development overlies the shallow aquifer and subcrop of the Black Warrior River aquifer. Development of the urban area began about 1965 and continued in some areas through 1995. The average home is built on a 1/8- to 1/4-acre lot.

Ground-water samples were collected from 29 wells in the agricultural area, 30 wells in the urban area, and a reference well located in a predominately forested area. The median depth to the screens of the agricultural and urban wells was 22.5 and 29 feet, respectively. Ground-water samples were analyzed for physical properties, major ions, nutrients, and pesticides. Samples from 8 of the agricultural wells and all 30 urban wells were age dated using analyses of chlorofluorocarbon, sulfur hexafluoride, and dissolved gases. Ground water sampled from the agricultural wells ranged in age from about 14 to 34 years, with a median age of about 18.5 years. Ground water sampled from the urban wells ranged in age from about 1 to 45 years, with a median age of about 12 years. The ages estimated for the ground water are consistent with the geology and hydrology of the study area and the design of the wells.

All of the agricultural and urban wells sampled for this study produce water from the shallow aquifer that overlies and recharges the Black Warrior River aquifer, or from the uppermost unit of the Black Warrior River aquifer. The wells are located in the same physiographic setting, have similar depths, and the water collected from the wells had a similar range in age. Statistically significant differences in ground-water quality beneath the agricultural and urban areas can reasonably be attributed to the effects of land use.

Ground water from the agricultural wells typically had acidic pH values and low specific conductance and alkalinity values. The water contained few dissolved solids, and typically had small concentrations of ions. Some of the agricultural ground-water contained concentrations of ammonia, nitrite plus nitrate, phosphorus, orthophosphate, and

dissolved organic carbon in concentrations that exceeded those typically found in ground water. Pesticides were detected in ground water collected from 25 of the 29 agricultural wells. Nineteen different pesticide compounds were detected a total of 83 times. Herbicides were the most frequently detected class of pesticides. The greatest concentration of any pesticide was an estimated value of 1.4 microgram per liter of fluometuron.

The Wilcoxan rank sum test was used to determine statistically significant differences in water quality between the agricultural and urban ground water. Ground water from the agricultural and urban areas had a similar range of values for most physical properties, major ions, and age. Ground water from the agricultural area contained statistically greater concentrations of magnesium than ground water from the urban area. Fewer pesticide compounds were detected in the agricultural ground water than in the urban ground water. The total number of pesticide detections also was less in the agricultural ground water than in the urban ground water. Atrazine was the only manmade compound detected frequently enough in both data sets to allow statistical comparison. There was no statistical difference in atrazine concentrations between ground water from the agricultural and urban areas.

The Spearman rho and Kendall tau tests were used to test for statistically significant covariance among selected constituents in the agricultural ground water and for crop type. The concentration of nitrite plus nitrate increased as the concentration of magnesium and the number of pesticides detected increased. This correlation is attributed to land application of nitrogen-based fertilizer to enhance yield, crushed limestone and dolomite (which contain magnesium) to raise the acidic pH of the soil, and to the application pesticides. No correlation was found between crop type and ground-water quality, the concentrations of pesticides, or the number of pesticides detected in the agricultural ground water. This lack of correlation probably is a result of such practices as crop rotation and the simultaneous cultivation of a variety of crops.

INTRODUCTION

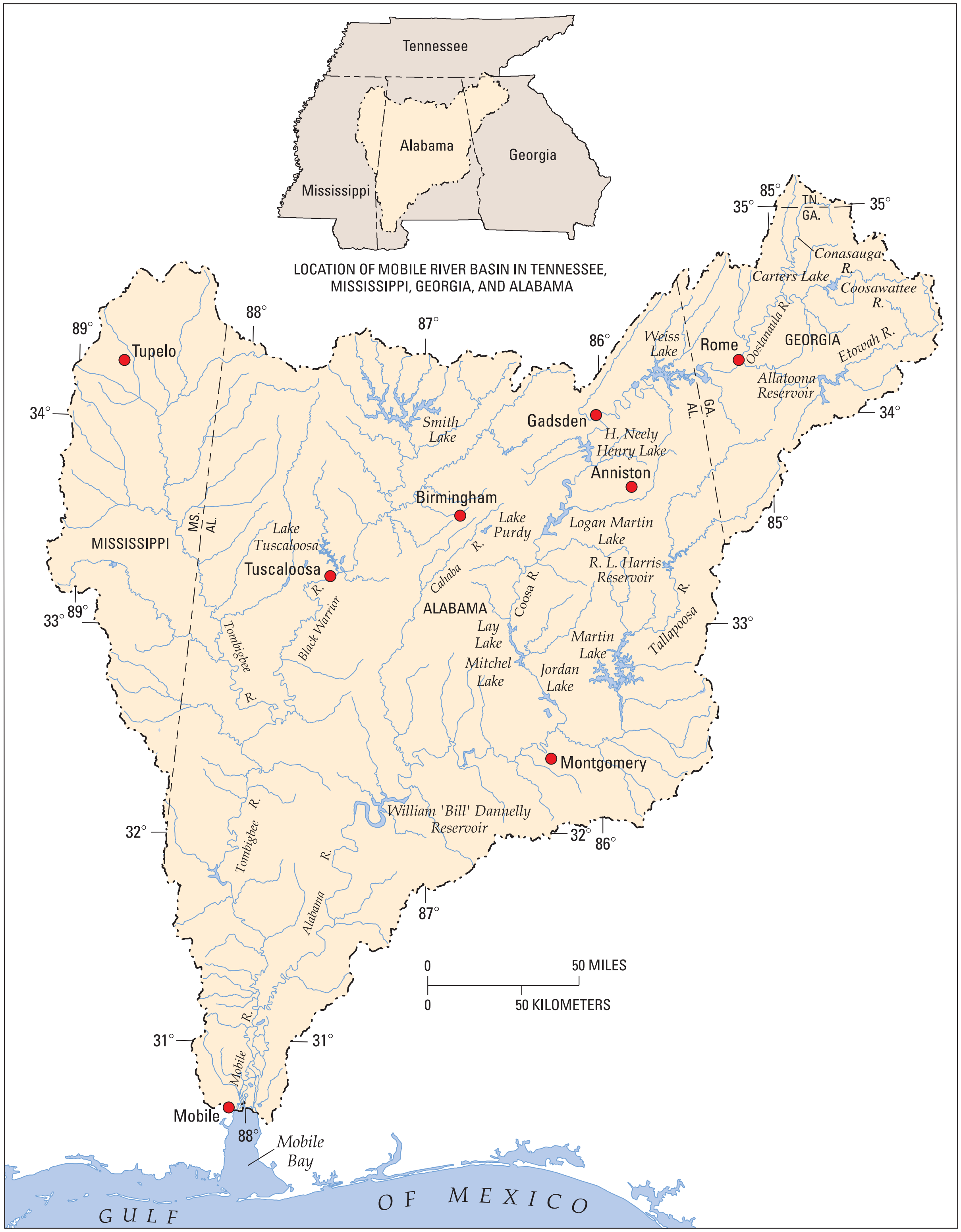
Ground water is the source of drinking water for approximately 50 percent of the Nation (U.S. Geological Survey, 1999a). Degradation of ground-water quality as a result of various land-use practices is a major concern, not only because of its use for public water supply, but also because of the potential for ground water to affect surface-water quality. This study examined the effects of agricultural and urban land use on shallow ground-water quality in the Mobile River Basin (fig. 1).

Agriculture in the Mobile River Basin is concentrated in the flood plains of the major rivers and their tributaries. The primary row crops include corn, soybeans, cotton, wheat, and sorghum (Johnson and others, 2002). Land use in the urban area, which is located in eastern Montgomery, Alabama, is primarily a mixture of high- to low-density residential, commercial, light industry, and forested areas. The agricultural and urban wells sampled for this study produce water from the same aquifers, are located in the same physiographic settings, and have similar ranges and median values for depth.

The U.S. Geological Survey (USGS) National Water-Quality Assessment (NAWQA) Program was designed to assess the status and trends in the quality of the ground- and surface-water resources in the Nation’s major river basins (also referred to as Study Units); and to link the status and trends in order to better understand the natural and human factors that affect the quality of water (Gilliom and others, 1995). The study described in this report is part of the NAWQA Program investigation of the Mobile River Basin in Alabama, Georgia, Mississippi, and Tennessee (fig. 1).

Purpose and Scope

The purposes of this report are to describe and compare ground-water quality in a shallow aquifer and the shallow subcrop of the Black Warrior River aquifer beneath agricultural and urban land-use areas of the Mobile River Basin. Hydrologic and geologic data collected during the drilling of 60 wells were used to describe the hydrogeology of the shallow aquifers. Water-quality samples were collected from 29 agricultural wells, 30 urban wells, and 1 reference well located in a forested area. All ground-water samples were analyzed for physical properties, major ions, nutrients, and pesticides. Samples from 8 agricultural wells and 30 urban wells were analyzed for chlorofluorocarbons, dissolved gases, and sulfur hexafluoride to estimate the recharge date (age) of the water. Ground-water samples were collected from the urban wells from October 1999 through January 2000,



Base from U.S. Geological Survey digital data, 1:250,000, 1994
Universal Transverse Mercator projection,
Zone 16

Figure 1. Locations of major rivers and cities in the Mobile River Basin (from Robinson, 2002).

and from the agricultural and reference wells from June through December 2001. Nonparametric statistical analysis was used to check for significant differences between agricultural and urban ground-water quality. Correlation analysis was used to determine covariance between selected factors, such as land use, well depth, crop type, and ground-water quality.

Previous Investigations

Reports that describe the geology of the study area date back approximately 140 years when Tuomey (1858) included a report on part of the Cretaceous Formations of Alabama in the second biennial report of the Geological Survey of Alabama. Osborne and others (1989) prepared the current geologic map of Alabama; and King and Biekman (1974) prepared a geologic map of the conterminous United States, from which the geologic map for the Mobile River Basin (fig. 2) was derived.

Reports describing the ground-water resources for the agricultural and urban land-use areas date back to Smith (1907). Scott (1957, 1960a, 1960b) describes the ground-water resources of Lowndes, Autauga, and Macon Counties, respectively. Gillett and Hunter (1990) prepared a report describing the water resources of Lowndes County. Knowles and others (1960, 1963) published the results of an exhaustive study of the geology and ground-water resources of Montgomery County. A report by Paulson and others (1962) summarizes the ground-water resources and geology of Tuscaloosa County, Alabama. Lines (1975) describes the water resources of Elmore County, Alabama. DeJarnette and Crownover (1987) and Scott and others (1987) prepared reports describing the geohydrology and susceptibility of major aquifers to surface contamination for areas encompassing the agricultural land-use area. Water quality of the Black Warrior River aquifer (BWRA) in rural areas, and in a residential and commercial area of Montgomery, Alabama, was summarized in Robinson (2002). The results of analyses of ground water collected from the rural, urban, and agricultural wells were published in Pearman and others (2000, 2001, 2002, 2003). The nomenclature documented by Miller (1990) and Renken (1998) for the ground-water aquifer systems in the Mobile River Basin is used herein.

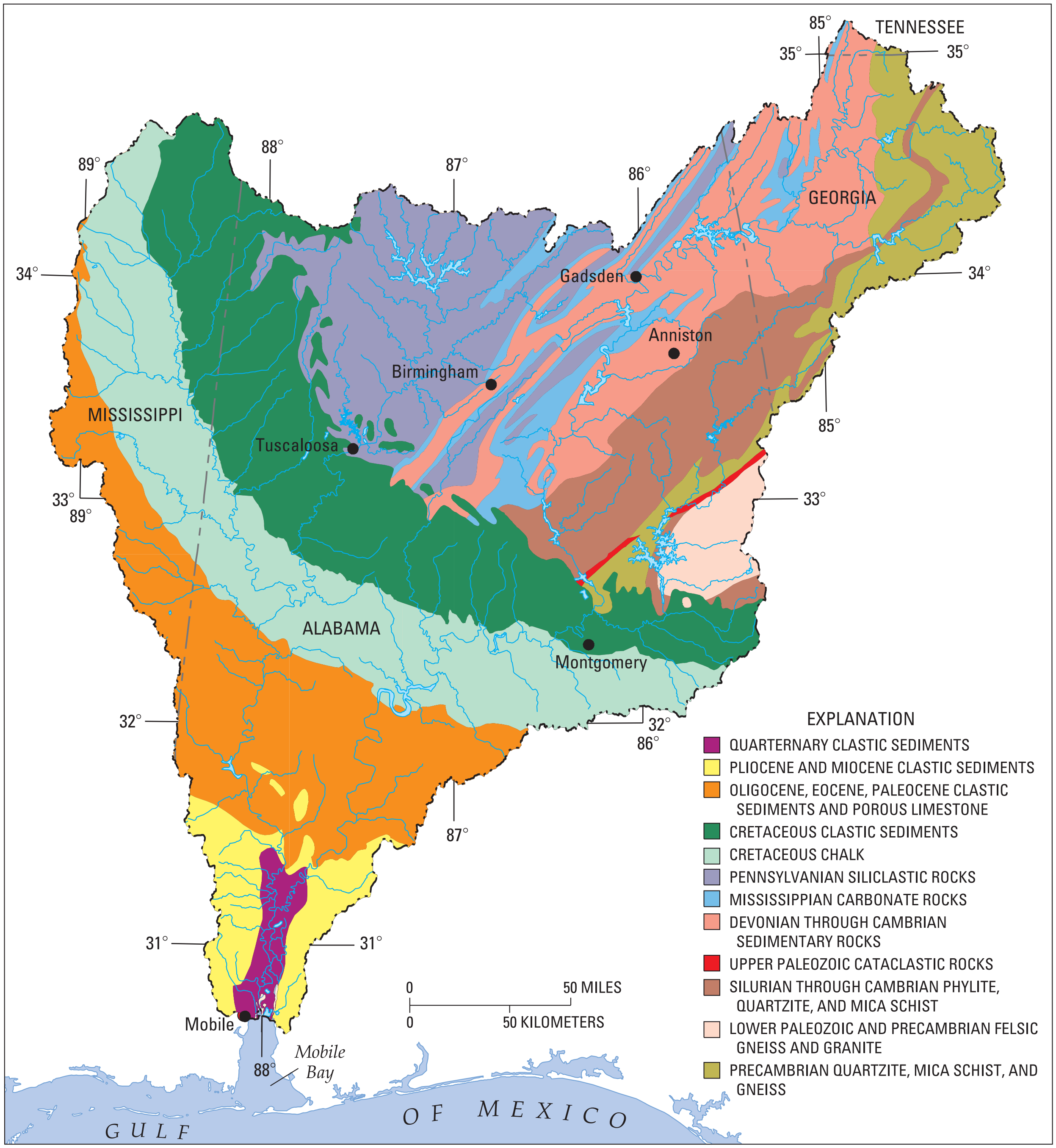
Acknowledgments

The author gratefully acknowledges the cooperation and assistance provided by the many private citizens of Alabama who allowed access to their property for data collection. W.T. Dozier, Clifford W. Cleveland, II, Milton A. Wendland, Lloyd Emfinger, Jr., Paul Taylor, and Tony Cofer of the Alabama Department of Agricultural and Industries; Charles Mitchell and James Bannon of Auburn University; Pam Mason, David Barrow, and John Harris of the U.S. Department of Agriculture-Natural Resources Conservation Service; and Andrew Farqhuer of the Alabama Department of Corrections all deserve special thanks for their help.

ENVIRONMENTAL SETTING OF THE MOBILE RIVER BASIN

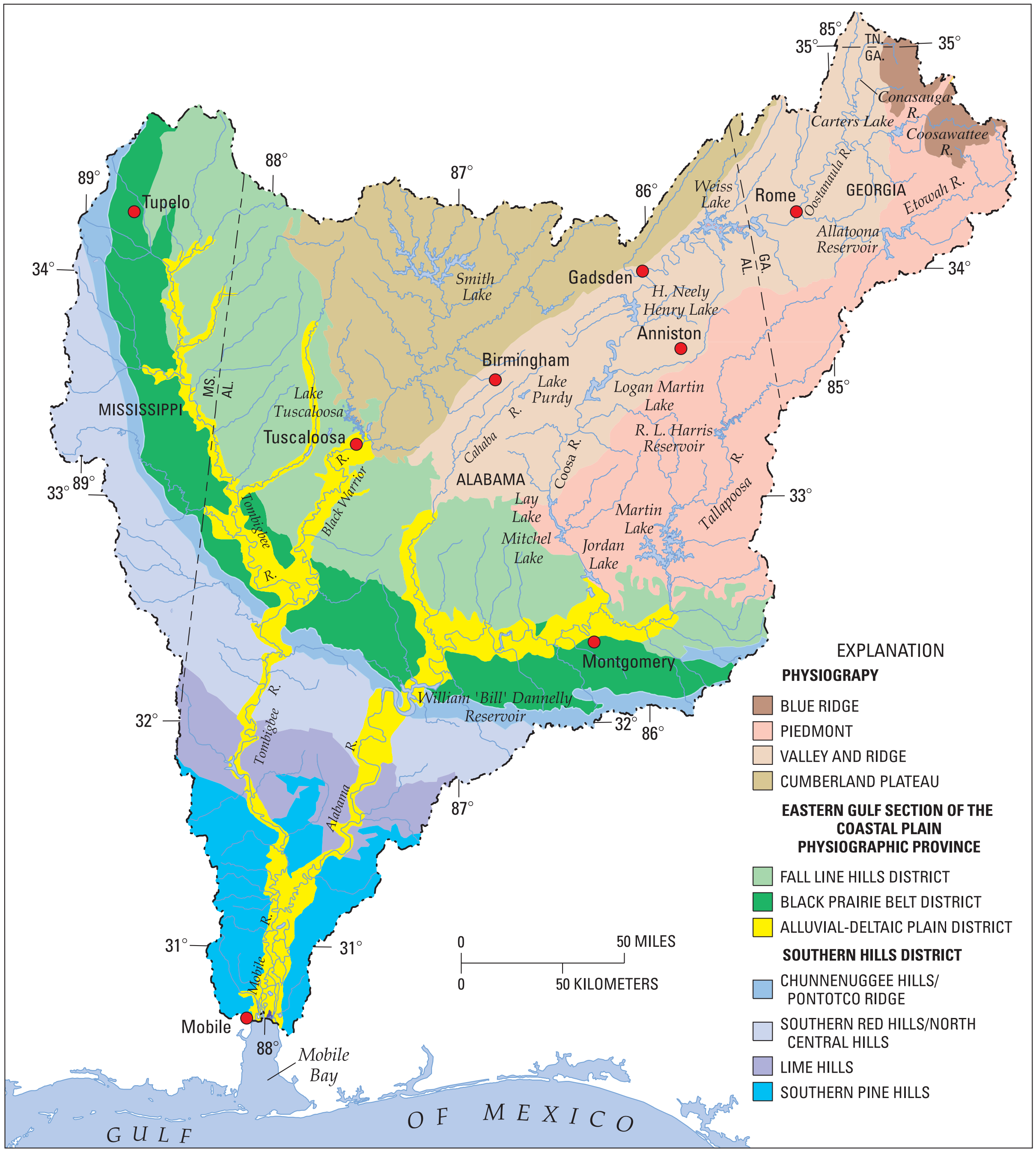
The Mobile River Basin encompasses about 44,000 square miles (mi^2) in Alabama, Georgia, Mississippi, and Tennessee (fig. 1). The major surface-water systems are the Cahaba, Coosa, and Tallapoosa, which are tributary to the Alabama River; and the Black Warrior River, which is tributary to the Tombigbee River (fig. 1). The Alabama and Tombigbee Rivers join to form the Mobile River in the southern part of the basin. The Mobile River Basin has diverse geology (fig. 2) and physiography (fig. 3). A detailed discussion of the Mobile River Basin environmental setting is presented by Johnson and others (2002).

Ground water is an important resource in the Mobile River Basin. Total ground-water use in 1995 was estimated to be about 328 million gallons per day (Mgal/d) [table 1; Strom and Mallory (1995), Fanning (1997), and Mooty and Richardson (1998)], which accounted for about 24 percent of the total water use in the basin. Ground-water withdrawals are concentrated in the Black Warrior River aquifer (166 Mgal/d), which is composed of clastic sediments of Cretaceous age, and in the Valley and Ridge aquifers (83 Mgal/d), which are solution-conduit aquifers developed in carbonate rocks of Devonian through Cambrian age (fig. 2). Fifty-one percent of the ground water used for public water supply in the Mobile River Basin is withdrawn from the Black Warrior River aquifer (table 1). In the outcrop and shallow subcrop areas, the Black Warrior River aquifer is susceptible to contamination due to the effects of land use.



Base from U.S. Geological Survey digital data, 1:2,000,000
Geology modified from King and Beikman, 1974.

Figure 2. Generalized geology of the Mobile River Basin (from Robinson, 2002).



Base from U.S. Geological Survey digital data, 1:2,000,000, digital data, 1972
Modified from Stephenson and Monroe, 1940; Sapp and Emplaincourt, 1975; and O'Hara, 1996

Figure 3. Physiographic units of the Mobile River Basin (from Robinson, 2002).

Table 1. Ground-water resources of the Mobile River Basin

[Modified from Miller, 1990; Strom and Mallory, 1995; Fanning, 1997; Mooty and Richardson, 1998; and Renken, 1998; Mgal/d, million gallons per day]

Regional aquifer subunit	Physiographic districts (fig. 3)	Primary geology (fig. 2)	Total population served (1995), in thousands	Total withdrawals (1995), in Mgal/d
Black Warrior River aquifer	Fall Line Hills, Alluvial-Deltaic Plain, Black Prairie Belt	Cretaceous clastic sediments overlain by clastic sediments of the Alluvial-Deltaic and Coastal Plain	885	166
Valley and Ridge aquifers	Valley and Ridge	Devonian through Cambrian carbonate rocks	429	83
Pearl River, Chickasawhay River, surficial aquifers	Southern Hills, Alluvial-Deltaic Plain	Oligocene, Eocene, and Paleocene clastic sediments and carbonate rocks	179	41
Piedmont and Blue Ridge aquifers	Piedmont and Blue Ridge	Igneous and metamorphic rocks of various and uncertain age	192	21
Appalachian Plateaus aquifers	Cumberland Plateaus	Pennsylvanian and Mississippian sandstone and carbonate rocks	130	17

Description of the Study Area

The study area lies within the flood plains of the Alabama, Coosa, Tallapoosa, and Black Warrior Rivers and their tributaries in the Alluvial-Deltaic Plain and Black Prairie Belt Physiographic Districts of the Coastal Plain Physiographic Province in central Alabama (fig. 3). Land-surface gradients generally are low to very low. Mixed deciduous and evergreen forests grow on the sandy, silty loam soil. Open pit sand and gravel mines operate near the major rivers. Abandoned pits fill with water and are sometimes used to irrigate crops.

The agricultural area lies within six counties: Autauga, Elmore, Lowndes, Macon, Montgomery, and Tuscaloosa (fig. 4). In Alabama, row cropping occurs primarily within the flood plains of the major rivers and their tributaries. The primary row crops grown in the Mobile River Basin include cotton, corn, soybeans, wheat, and sorghum (Johnson and others, 2002).

The urban area is located in eastern Montgomery, Alabama (fig. 4). The population of the Montgomery metropolitan area in 1998 was approximately 321,000 (U.S. Census Bureau, 2000). Land use in eastern Montgomery is primarily a mixture of high- to low-density residential, commercial, light industry, and forested areas.

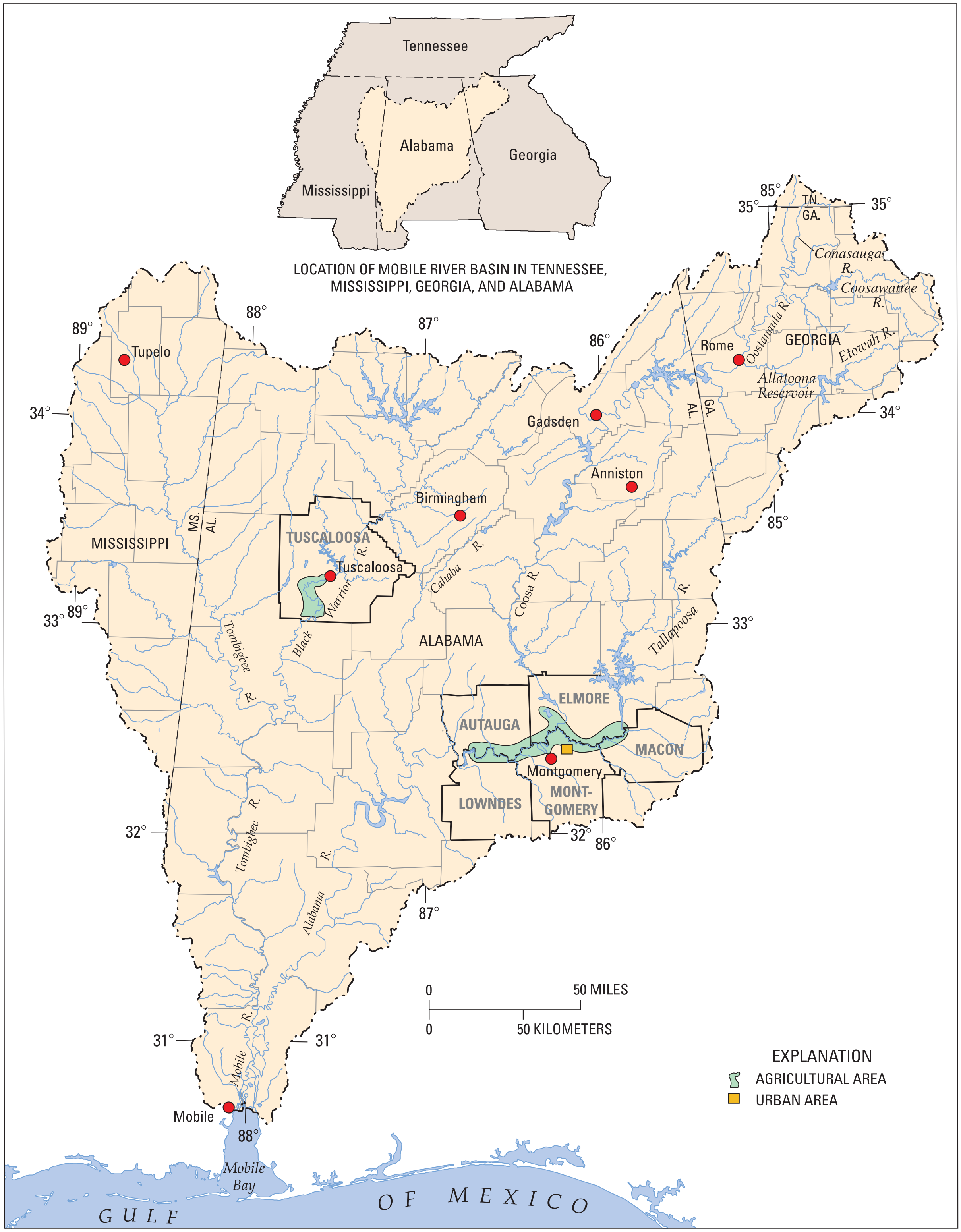
Mixed agriculture is typical, and multiple crop types are grown on many farms. Farming practices include no-till planting, rotating cotton and corn, and leaving fields fallow for a season. Many farmers also maintain pasture for cattle. Many of the farms are operated by second- or third-generation descendants of the original owners. This made it possible to determine that land use in the vicinity of most of the agricultural wells has not changed substantially in 25 to 50 years. Average farm size ranged from 196 to 524 acres

Table 2. Selected 1992 and 1997 statistics for agricultural study area, by county

[Data from the U.S. Department of Agriculture, www.nass.usda.gov/census/census97/highlights/ag-state.htm, accessed January 2003]

County	Average farm size (acres)	Acres of cotton	Acres of corn for grain or seed	Acres of soybeans	Acres of wheat for grain
Autauga	301	9,956	1,035	1,381	1,340
Elmore	222	19,393	2,167	1,371	640
Lowndes	524	7,725[a]	2,575	4,126[a]	no data
Macon	424	5,964	1,045	455	330
Montgomery	368	1,372	975	2,241	722
Tuscaloosa	196	4,313	4,464	2,118	1,162
Total acres		48,723	12,261	11,692	4,194

[a] 1997 data not reported, data from 1992 were used.



Base from U.S. Geological Survey digital data, 1:250,000, 1994
Universal Transverse Mercator projection,
Zone 16

Figure 4. Location of agricultural and urban study areas in the Mobile River Basin.

(table 2). Selected agricultural statistics for 1992 and 1997, published by the U.S. Department of Agriculture, show extensive row cropping for cotton, corn, soybeans, and wheat in the agricultural study area (table 2).

Hydrogeology of the Study Area

The study area is underlain, north to south, by alluvial and terrace deposits of gravel, sand, and clay; and by sands and clays of the uppermost part of the Black Warrior River aquifer (figs. 5 and 6). The alluvial and terrace deposits range from about 5 feet (ft) to more than 100 ft thick and form a shallow aquifer (figs. 5 and 6) that overlies the uppermost part of the Black Warrior River aquifer with little or no hydraulic separation (DeJarnette and Crownover, 1987; Scott and others, 1987).

Average annual rainfall in central Alabama ranges from about 51 to 57 inches (in.) (National Oceanic and Atmospheric Administration, 1999). Rainfall is seasonally distributed, with the greatest rainfall amounts occurring during the months of December through March [about 5–6 inches per month, (in/mo)]; and the smallest rainfall amounts occurring during the months of August through October (about 2–4 in/mo). Surface water drains to the Alabama, Coosa, Black Warrior, and Tallapoosa Rivers. North of the Cretaceous chalk (figs. 2, 5, and 6), the Black Warrior River aquifer receives recharge directly from precipitation where the aquifer is exposed at land surface or is overlain by permeable sand and gravel with no intervening unit of low permeability (Hinkle and others, 1983; Scott and others, 1987).

STUDY DESIGN AND METHODS

This study was designed by following national guidelines (Gilliom and others, 1995; Squillace and Price, 1996), and ground-water sampling protocols (Lapham and others, 1997; Koterba and others, 1995) for NAWQA. Standardization of data-collection

<table>
<tr><th>System</th><th colspan="2">Stratigraphic unit</th><th>Major lithology</th><th>Thickness (feet)</th><th>Hydrogeologic unit</th><th>Regional aquifer system</th></tr>
<tr><td>Quaternary</td><td colspan="2">Alluvial and terrace deposits</td><td>Sand, gravel, silt, and clay</td><td>5–100 +</td><td>Shallow aquifer</td><td></td></tr>
<tr><td rowspan="4">Cretaceous</td><td colspan="2">Selma Chalk</td><td>Chalk</td><td>0–200 +</td><td>Confining unit</td><td rowspan="4">Southeastern Coastal Plain Aquifer System</td></tr>
<tr><td></td><td>Eutaw Formation</td><td>Upper and lower marine sand separated by clay; consists of glauconitic sand interbedded with calcareous sandstone and sandy limestone</td><td>0–100 +</td><td rowspan="3">Black Warrior River aquifer</td></tr>
<tr><td rowspan="2">Tuscaloosa Group</td><td>Gordo Formation</td><td>Basal zone of gravel and sand overlain by lenticular beds of sand and clay</td><td>0–200 +</td></tr>
<tr><td>Coker Formation</td><td>Basal zone of non-marine sand, gravel, and clay;
upper zone of marine sand and clay</td><td>500 +</td></tr>
<tr><td colspan="3">Pre-Cretaceous</td><td>Schist, gneiss</td><td>1,000 +</td><td>Base of fresh-water flow system</td><td></td></tr>
</table>

Figure 5. Generalized section of stratigraphic and hydrogeologic units underlying the agricultural and urban study areas in the Mobile River Basin (after Scott, 1960b; Paulson and others, 1962; Knowles and others, 1963; Scott and others, 1987; Gillett and Hunter, 1990; Miller, 1990).

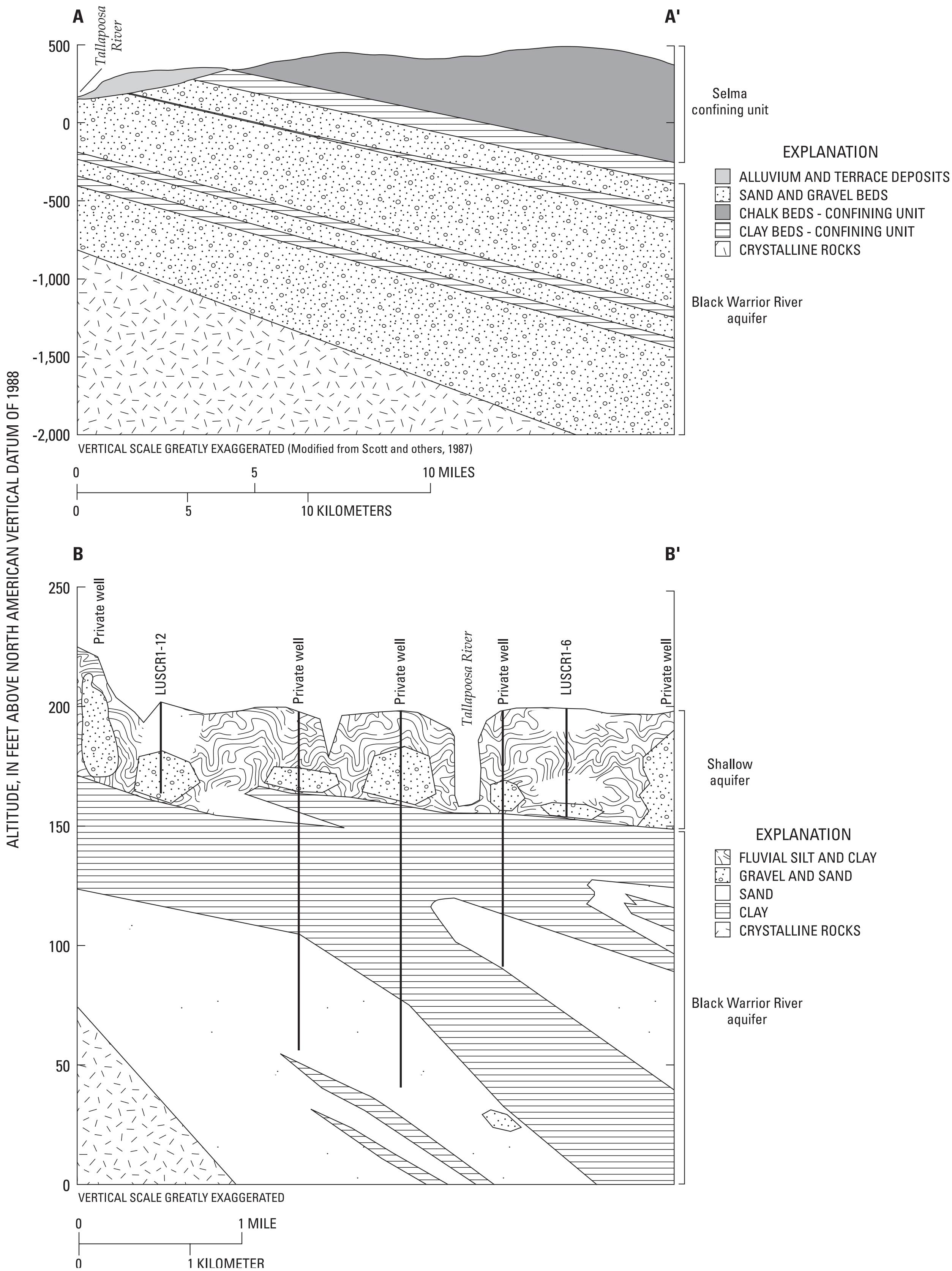


Figure 6. Diagram showing generalized hydrogeologic sections A-A′ and B-B′ in the agricultural and urban study areas of the Mobile River Basin (from fig. 7).

procedures is intended to produce a nationally consistent data base that can be used to produce statistically valid interpretations. Modification of national protocols is sometimes necessary, however, because of local conditions. The following sections describe how these national protocols were applied and, when necessary, modified for this study.

Land Use and Land Cover

The criteria used to select well locations in the agricultural area (fig. 7) are outlined in Gilliom and others (1995). The two primary considerations for the placement of the agricultural wells were that (1) ground water sampled from the wells should be recently recharged (generally less than 10 years old), and (2) row cropping be the predominant land use in the vicinity of sampled wells (table 3). This enabled direct assessment of relations between land-use activity and ground-water quality (Gilliom and others, 1995). Where row cropping was not the predominant land use surrounding the well, the well was located downgradient from a row cropping area.

Well locations for the urban area (fig. 7) were selected based on the criteria outlined in Squillace and Price (1996). Of primary concern were the criteria specifying that (1) the shallow aquifer in the study area be used as a source of drinking water, a potential source of drinking water, or hydraulically connected to surface water or deeper ground water that is used as a source of drinking water, and (2) land use within the study area be residential and commercial developed between 1970 and the 1990's. The urban study area in eastern Montgomery met these criteria; however, the last criterion was modified to extend the period of residential development in the study area from 1960 to 1998.

Monitoring Well Network

The wells used for this study were designed to sample shallow ground water. Of the 30 agricultural wells, 29 were installed by the USGS in accordance with NAWQA protocols (Lapham and others, 1995, 1997; Koterba, 1998). One existing well (LUSCR1-15) that met NAWQA well-design protocols also was sampled. One well (LUSCR1-8) could not be sampled during the study because it remained dry (table 3; fig. 7). A reference well (LUSCR1-21) was installed in the flood plain of the Alabama River (fig. 7) at approximately the same depth as the wells located in the agricultural and urban areas. The reference well was located in a predominately forested area to obtain a sample of ground water that is relatively unaffected by man.

The agricultural wells were completed in the alluvial deposits (19 wells), the terrace deposits (7 wells), and the Eutaw Formation (4 wells). The urban wells were completed in the alluvial deposits (8 wells), terrace deposits (6 wells), and the Eutaw Formation (16 wells). Detailed information about the urban wells used to sample water beneath the Montgomery, Alabama, area is documented in Robinson (2002).

Water flows into a well through the well screens. In general, the less the depth to the well screen, the greater the susceptibility of the well to contamination from sources at land surface. The depth to the well screens of the agricultural wells ranged from about 11 to 46 ft, with a median depth of 22.5 ft. The depth to the well screens of the urban wells was slightly greater, ranging from about 8 to 88 ft, with a median depth of 29 ft.

A variety of physical and hydraulic data were collected during the installation of the agricultural and urban wells. Representative samples of the alluvial and terrace deposits and the Eutaw Formation were collected during installation of the agricultural and urban wells. Lithologic descriptions of the sediments were prepared. Sediment cores were collected from each lithologic unit. Representative samples of each lithology were chilled and sent to the USGS National Water Quality Laboratory (NWQL) in Denver, Colorado, for organic carbon analyses. A slug test was performed in well LUSCR1-6, which is located about 1,100 ft south of the Tallapoosa River near Milstead, Alabama (figs. 6 and 7). The results of the slug test were used to estimate the hydraulic conductivity of the alluvial deposits in which the well is completed.

Water-Quality Samples

Ground-water samples were analyzed for physical properties, major ions, nutrients, pesticides, chlorofluorocarbons (CFCs), sulfur hexafluoride (SF_6), and dissolved gases. The laboratory analytical methods used are listed in table 4. Sampling procedures and field methods were consistent with NAWQA ground-water sampling protocols (Koterba and others, 1995) and standard USGS procedures. Ground-water

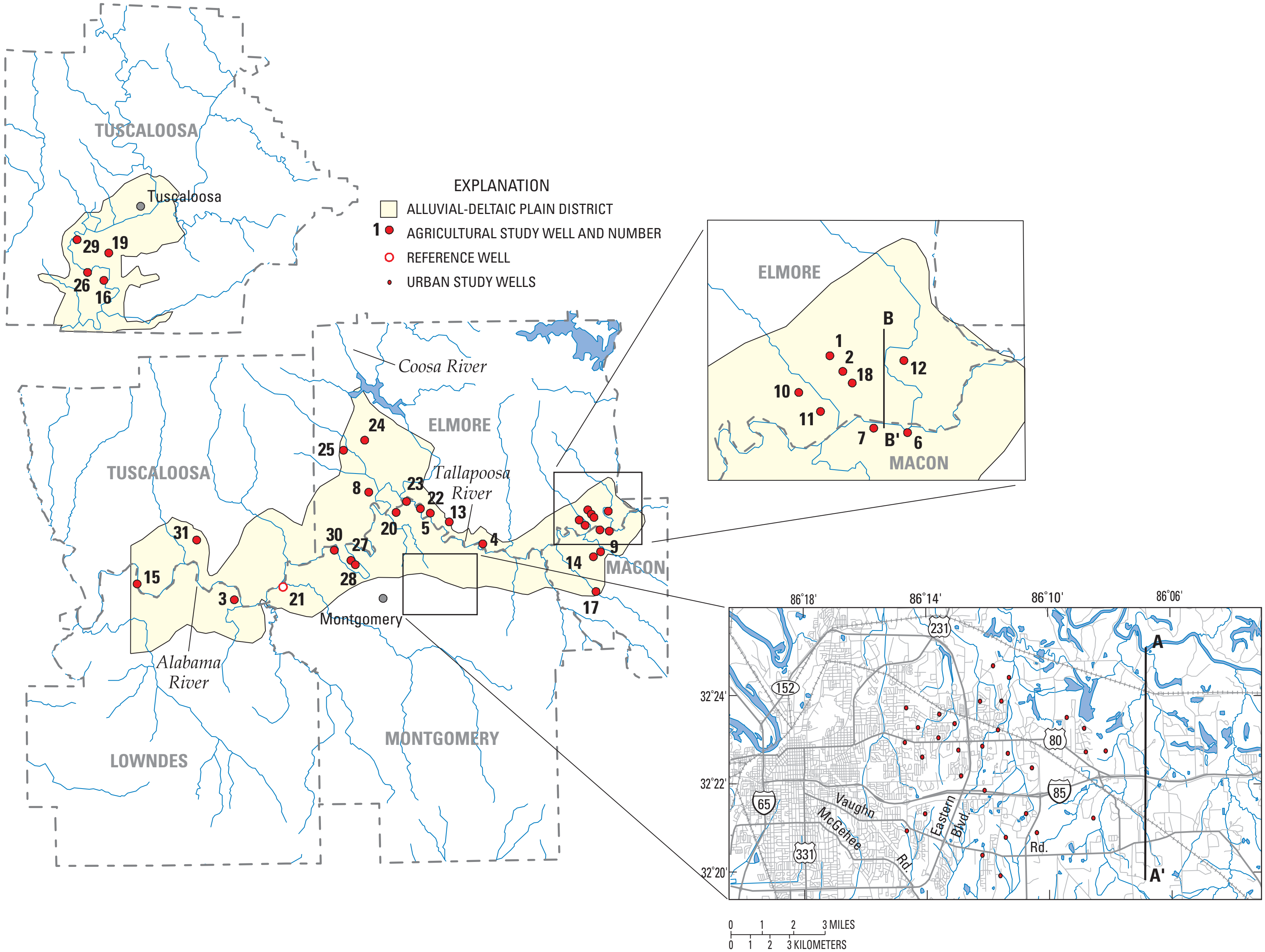


Figure 7. Locations of agricultural and urban wells sampled in the Mobile River Basin, and lines of sections A-A′ and B-B′.

Table 3. Predominant crop and land-use types within a 0.3-mile radius of the agricultural wells in the Mobile River Basin

Well (fig. 7)	Cotton, in percent	Corn, in percent	Other crops[a] in percent	Pasture, in percent	Fallow fields, in percent	Other[b], in percent
LUSCR1-1	93.5					6.5
LUSCR1-2	86.5					13.5
LUSCR1-3	37.5					62.5
LUSCR1-4	39			3.8		57.2
LUSCR1-5	10			25.2		64.8
LUSCR1-6	25.3	12.6			11.2	50.9
LUSCR1-7	6.5	26		4.3		63.2
LUSCR1-8[c]	4.6	13.3		14.7		67.4
LUSCR1-9		30.8				69.2
LUSCR1-10	91.5					8.5
LUSCR1-11	37.1	26.6		24.8		11.5
LUSCR1-12	66.4					33.6
LUSCR1-13	49.1	20.1		3.9		26.9
LUSCR1-14	71.9					28.1
LUSCR1-15	34.1					65.9
LUSCR1-16		20.4				79.6
LUSCR1-17	19.1	22.4		5.4		53.1
LUSCR1-18	90.3					9.7
LUSCR1-19	43.8					56.2
LUSCR1-20					12.4	87.6
LUSCR1-21[d]						100
LUSCR1-22			40.1			59.9
LUSCR1-23		59.5	3.1	10		27.4
LUSCR1-24		47.9	12	27.5		12.6
LUSCR1-25		24.5	6.1			69.4
LUSCR1-26	45.7					54.3
LUSCR1-27	80.1					19.9
LUSCR1-28	69.4					30.6
LUSCR1-29	51.2					48.8
LUSCR1-30	57.2		3.9			38.9
LUSCR1-31	41.7					58.3

[a] Soybeans, sorghum, or wheat.
[b] Open water, forested, roads, drainages, utility rights-of-way, housing, mining.
[c] Dry well, not sampled for this study.
[d] Reference well.

Table 4. Constituents analyzed and analytical methods used for agricultural ground-water samples collected in the Mobile River Basin

[UV, ultraviolet; C-18, octadecyl; CFC, chlorofluorocarbons; ECD, electron capture detector; SF_6, sulfur hexafluoride]

Constituent	Number of samples	Analysis method	Reference
Major ions	28[a]	Atomic absorption spectrometric	Fishman (1993)
Nutrients	29	Various methods	Fishman (1993)
Organic carbon	29	UV-promoted persulfate oxidation and infrared spectrometry	Brenton and Arnett (1993)
Pesticides	29	Solid-phase extraction using a C-18 cartridge and gas chromatography/mass spectrometry	Zaugg and others (1995) Furlong and others (2001)
CFC	8	Gas chromatography with ECD detector	Busenberg and Plummer (1992)
SF_6	8	Gas chromatography with ECD detector	Busenberg and Plummer (2000)

[a] One sample was filtered to remove flocculants that formed after sampling; no dissolved ion data are available for this sample.

samples analyzed for CFCs, SF_6, and dissolved gases were hand delivered to the CFC laboratory in Reston, Virginia. All other ground-water samples were chilled and shipped overnight to the NWQL in Denver, Colorado.

Physical properties of water samples that are commonly measured in the field include pH, specific conductance, alkalinity, and dissolved oxygen. These measurements are made on site, because values or concentrations may change once the water is removed from the source. For comparison of sample stability, these measurements were made at the time of sampling, and again by the NWQL. The difference between the two measurements for each property ranged from less than 1 to 10 percent, but was typically less than 5 percent. Measurements for physical properties made at the NWQL are listed in table 7.

Ground water collected from the agricultural and urban wells was analyzed for 109 different pesticides and pesticide degradation products. These compounds are grouped into two NWQL schedules—2001 and 2060—for testing by a specific set of preparation techniques, equipment, and analytical procedures. The urban ground water was analyzed for the compounds listed on NWQL schedule 2060 (Appendix table 1 and 2); but these data were not published in Robinson (2002) because the 2060 analytical method, then classified as NWQL Lab Code 9060, was an experimental method prior to August 2001, and results of analyses were considered to be conditional.

The NWQL reports analyte concentrations as measured, estimated (censored), or less than a reporting value. These terms indicate the confidence the laboratory places in the accuracy of the measurement and are based on the long-term accuracy of the methods used. The method detection level (MDL) is the minimum concentration of a substance that can be measured and reported with 99-percent confidence that the analyte concentration is greater than zero. The long-term method detection level (LTMDL) is derived by determining the MDL for a minimum of 24 MDL spike-sample measurements over an extended period of time. The laboratory reporting level (LRL) generally is equal to twice the yearly determined LTMDL.

Measured values are reported for concentrations above the LRL and within the calibration range of the apparatus. Estimated values are reported for concentrations less than the LRL but above the LTMDL (Childress and others, 1999) or for concentrations greater than the calibrated range of the apparatus. The value of the LRL is reported with a "less than" remark code for samples in which the analyte was not detected.

The laboratory reporting levels of the analytical methods used by the NWQL vary with time. Comparison of detection frequencies among sample sets can be misleading because of the different LRLs. Pesticide data are sometimes adjusted by censoring to a common threshold (values less than the threshold are not considered detections) to reduce this type of bias. Pesticide data for the agricultural and urban areas were censored to a common threshold for this report so that detection frequencies between the two study areas could be compared.

Quality-Assurance and Quality-Control Procedures

Quality-assurance (QA) procedures developed for NAWQA investigations were followed for this study. Well selection and well installation procedures were based on the standards documented by Lapham and others (1995, 1997). Description and classification of land use in the vicinity of the agricultural wells followed the procedures of Koterba (1998). Water-quality samples were collected and documented using the protocols and procedures of Koterba and others (1995).

Three types of quality-control (QC) samples were collected during the study—blanks, spikes, and replicates (table 5). A blank sample is a water sample that contains no analytes of interest. A blank sample is analyzed to determine if contamination has occurred during (1) sample collection and processing, (2) sample handling and transportation, and (or) (3) sample analysis (Mueller and others, 1997). Spiked samples are injected with a known mass of an analyte of interest for use in determining (1) the accuracy and precision of organic analyses, (2) the stability of analytes during typical holding times, and (3) whether characteristics of the environmental sample may interfere with the analysis for analytes (Mueller and others, 1997). Replicates are two or more samples that are either split, collected in sequence, or collected concurrently; replicates are considered to have identical composition. Replicates provide a measure of the variability resulting from sample collection, processing, and analysis (Mueller and others, 1997). Analyses of blanks, spikes, and replicates are evaluated to detect systematic bias in sample analyses results.

Table 5. Summary of quality-control samples collected during sampling of the agricultural wells in the Mobile River Basin

Quality-control sample type	Analytical coverage	Number of samples
Blank	Inorganic compounds	4
Blank	Organic compounds	4
Spike	Pesticides	3
Spike-replicate	Pesticides	3
Replicate	Inorganic compounds	4
	Organic compounds	4
	Pesticides	6

The QC samples collected during sampling of the agricultural wells included four inorganic and organic blank samples, three pesticide spikes and three pesticide spike-replicates, four inorganic and organic replicates, and six pesticide replicate samples. Robinson (2002) summarized QC sample collection during sampling of the urban wells. Interpretation of the data provided by the blank samples collected during the agricultural land-use study indicated no systematic bias or source of contamination attributable to the sampling equipment or procedures used to collect the ground-water samples. Evaluation of the results of pesticide spike and environmental sample replicates, however, indicated a problem with NWQL pesticide schedule 2060. Mean recovery of pesticides from the spike and spike-replicate samples ranged from 58 to 83 percent (table 6). The mean difference in recovery between the spike and the spike-replicate samples ranged from 12.7 to 49 percent. The mean difference between concentrations of analytes for replicate samples ranged from 0 to 10.2 percent (table 6).

The small mean-recovery percentage for NWQL schedule 2060 pesticide-spiked samples (table 6) indicates that the analytical method for schedule 2060 underestimated the concentration of pesticides in the spiked samples. The large mean difference in recovery percentages for the schedule 2060 spike and spike-replicate samples indicates that the analytical method for schedule 2060 had poor accuracy. The large mean difference in analyte concentration for the schedule 2060 environmental replicate samples indicates poor precision. More information pertaining to NWQL schedules 2001 and 2060 is presented in appendix A. None of the environmental data were adjusted based on interpretation of the results of the QC samples; for the purposes of this report, the results of the schedule 2060 pesticide analyses are considered to be conservative.

Table 6. Descriptive statistics for quality-control samples collected for pesticide analysis during sampling of the agricultural wells in the Mobile River Basin

[NWQL, National Water Quality Laboratory]

Sample type	Date sampled	Mean recovery (percent)	Mean difference in recovery (percent)	Mean difference in concentration (percent)
NWQL Schedule 2001				
spike	07/19/2001	82		
spike-replicate	07/19/2001	93	3.9	
spike	09/10/2001	107		
spike-replicate	09/10/2001	116	2.4	
spike	09/20/2001	89		
spike-replicate	09/20/2001	90	0.7	
NWQL Schedule 2060				
spike	07/19/2001	83		
spike-replicate	07/19/2001	58	49.0	
spike	09/10/2001	79		
spike-replicate	09/10/2001	70	23.4	
spike	09/20/2001	83		
spike-replicate	09/20/2001	79	12.7	
NWQL Schedule 2001				
environmental	06/25/2001			0.1
replicate sample	06/25/2001			
environmental	07/19/2001			0.5
replicate sample	07/19/2001			
environmental	07/24/2001			3.7
replicate sample	07/24/2001			
environmental	08/08/2001			0.0
replicate sample	08/08/2001			
environmental	09/20/2001			0.0
replicate sample	09/20/2001			
NWQL Schedule 2060				
environmental	07/19/2001			5.3
replicate sample	07/19/2001			
environmental	07/24/2001			10.2
replicate sample	07/24/2001			
environmental	08/08/2001			0.5
replicate sample	08/08/2001			
environmental	09/10/2001			0.3
replicate sample	09/10/2001			
environmental	09/20/2001			0.0
replicate sample	09/20/2001			

Graphical and Statistical Methods

Two common graphical techniques were used to present and analyze the results of water-quality sampling—the Piper (1944) trilinear diagram and boxplots (Tukey, 1977). A Piper diagram plots the ionic content of many samples on a single graph. The dominant ion type in each sample is easily determined by where the sample plots on the diagram. However, because ion concentrations are converted to total composition percentages before plotting, water samples with very different total concentrations may plot closely together. Alley (1993) lists three ways boxplots illustrate the distribution of data: (1) the sample median, which is a robust measure of the central tendency of the data and is not influenced by outliers; (2) the difference between the top and bottom of the rectangle, the interquartile range, which is a robust measure of the spread of the data; and (3) the distance from the top of the rectangle to the median compared to the distance from the bottom of the rectangle to the median, which is a measure of the skewness of the data. Boxplots are useful in presenting data for individual constituents in large numbers of samples. Different groups of data can be compared and contrasted by placing boxplot analyses side by side.

Descriptive statistics, such as the range, maximum, minimum, and median, were used to summarize the distribution of chemical data for ground-water sample sets. Chemical constituents with large differences in median values in the two data sets were further evaluated using nonparametric hypothesis testing. Nonparametric statistical methods were chosen because environmental data typically are non-normally distributed, and significant percentages of the data are less than laboratory reporting levels.

Nonparametric hypothesis tests represent censored data by ranking the data; estimation of data values below reporting levels is not necessary. The Wilcoxon rank-sum test was used to test the null hypothesis that independent, random ground-water samples from two populations were identical. Rejection of the null hypothesis, at a confidence level of 95 percent, supported the alternative hypothesis that the samples were drawn from different populations.

Correlation analysis was used to examine the relations between selected physical properties and chemical constituents in ground water collected from the agricultural wells and the land use surrounding the wells. Correlation analysis is a means to assess not only the relation between two variables, but also the strength of the relation (Ott, 1988, p. 319). The Spearman rho rank correlation test was used to evaluate the correlation between water quality and land use since the number of samples was greater than 20 (Helsel and Hirsch, 1992, p. 217–218). The Kendall tau rank correlation test was used to evaluate the correlation among ground-water age, water quality, and land use since the number of samples was less than 10 (Helsel and Hirsch, 1992, p. 212). Scatterplots of all correlated variables were made to ensure that the variables possessed a monotonic correlation (Helsel and Hirsh, 1992, p. 209–211).

CHEMICAL AND PHYSICAL PROPERTIES OF THE SHALLOW SEDIMENTS

The chemical and physical properties of sediments through which ground water flows can affect ground-water quality. Soils with low organic carbon content may increase the potential for nitrate (U.S. Geological Survey, 1999b) and pesticides (Barbash and Resek, 1996) to enter ground water. Soils with low pH contribute to low pH conditions in ground water, which has been correlated with increased nitrate and trace element concentrations (van Duijvenbooden, 1993). Coarse-grained sediments permit more rapid infiltration of water than fine-grained sediments; as a result, aquifers overlain by coarse-grained sediments may be more vulnerable to surface contamination than aquifers overlain by fine-grained sediments. The chemical and physical properties of the shallow sediments that agricultural and urban wells are completed in were determined by field and laboratory testing.

Soil Characteristics

The study area is underlain by soils developed from the alluvial and terrace deposits, the Eutaw Formation, and the Selma Chalk. Sandy, silty loam developed from the alluvial and terrace deposits and the Eutaw Formation have soil pH values ranging from 3.6 to 6.5, and an organic carbon content ranging from 0 to 4 percent (Hearn, 1944, 1955; Hajek and others, 1975; Harris and Stubbs, 1977). Clayey loam developed from the Selma Chalk is very poorly drained, has soil pH values ranging from 4.5 to 8.5, and organic carbon content ranging from 0 to 7 percent (Burgess and others, 1960). The relatively high organic carbon content and more moderate pH of soils developed from the chalk may reduce the potential for pesticides, nitrate, and trace elements to enter the ground water. The lower soil pH and organic carbon content of soils developed from the alluvial and terrace deposits may increase the potential for pesticides, nitrate, and trace elements to enter the ground water.

Sediment Core Analyses

Sediment cores collected from the alluvial and terrace deposits and the Eutaw Formation had soil pH values ranging from 4.2 to 6.7, with a median value of 4.8. Organic carbon content ranged from less than 0.02 to 0.33 percent with a median value of 0.03 percent. The low pH and low organic carbon content of the aquifer materials may increase the mobility of trace elements, nitrates, and pesticides in the ground-water system.

Lithology of the Shallow Sediments

Samples of the alluvial deposits typically were composed of very fine- to very coarse-grained quartz sand that was clear, white, red, and yellow in color. Pebbles were present in some samples, and muscovite was common. Red, brown, and gray silt and clay were mixed with the sand, and also were present as separate layers. The lithology of the terrace deposit samples was similar to the alluvial deposits, but quartz gravel up to 100 millimeters in diameter also was present. Samples of the Eutaw Formation were composed of very fine- to medium-grained quartz sand, glauconite, calcium carbonate, and trace amounts of muscovite and pyrite. Gravel was not found in any of the Eutaw Formation samples.

Shallow Aquifer Properties

A slug test was performed in well LUSCR1-6, which is located about 1,100 ft south of the Tallapoosa River near Milstead, Alabama (figs. 6 and 7). The well is completed in alluvial sediments composed of very coarse-grained sand and gravel. These sediments form a shallow aquifer that overlies and recharges the Black Warrior River aquifer. The results of the test indicate a hydraulic conductivity of 90 feet per day (ft/d) for the material directly surrounding the well. Despite the great permeability indicated by the slug test, it is possible that water does not move quickly over long distances through the shallow aquifer. Sand and gravel deposits in flood plains occur as lenses of limited geographic extent and may not be physically connected to the surface-water drainage. Silts and clays of low permeability also are deposited in flood plains and may separate sand and gravel deposits from the surface-water drainage. In such a system, the primary direction of ground-water flow is horizontal through the aquifer material, and almost vertically downward through the silts and clays (Freeze and Cherry, 1979).

GROUND-WATER QUALITY

Agricultural ground-water quality was determined using samples collected from 29 wells. All of the wells in the agricultural area either produce water from the shallow aquifer that overlies and recharges the uppermost unit of the Black Warrior River aquifer or from the Black Warrior River aquifer. Ground water was collected from 29 agricultural wells and the reference well during June through December 2001. The ground water was analyzed at the NWQL for physical properties, major ions, nutrients (table 7), and pesticides. Agricultural ground-water quality was compared to the water quality of urban ground water collected in Montgomery, Alabama, during 1999–2000 (Robinson, 2002). Because the ground water collected from the agricultural and urban wells was taken from the same geologic units and physiographic setting, and at about the same depth, it is valid to compare and contrast the water quality of the two sample sets. Statistically significant differences in ground-water quality beneath the two land-use areas can reasonably be attributed to the effects of land use.

Physical Properties

Ground water collected from the agricultural wells typically had acidic pH values, low specific conductance and alkalinity values, and contained few dissolved solids. Comparison of the agricultural and urban ground-water quality indicates that agricultural ground water had approximately equal or slightly greater median values for physical properties but a smaller range of values for alkalinity, pH, total dissolved solids, and specific conductance compared to urban ground water (fig. 8). The Wilcoxon rank-sum test indicated no statistically significant difference in physical properties between urban and agricultural ground water. The values measured were consistent

Table 7. Minimum, median, and maximum values of selected physical properties and chemical constituents in ground water collected from agricultural and urban wells in the Mobile River Basin

[Min, minimum; Med, median; Max, maximum; µS/cm at 25 °C, microseimen per centimeter at 25 degrees Celsius; mg/L, milligram per liter; C, carbon; N, nitrogen; P, phosphorus; *, value is estimated by using a log-probability regression to predict the values of data below the method detection level (Maddy and others, 1990); none, no drinking-water standard; µg/L, microgram per liter; —, too few detections to estimate statistics; <, less than; E, concentration less than the reporting level but above the long-term method detection level]

Property or constituent	Drinking-water guideline	Reference well average value (2 samples)	Values for agricultural wells (29 samples)			Values for urban wells (30 samples)		
			Min	Med	Max	Min	Med	Max
Physical properties[a]								
pH (standard units)	6.5–8.5[b]	5.3	4.7	5.6	6.9	4.6	5.6	7.7
Specific conductance (µS/cm at 25 °C)	none	22	30	107	330	28	74	2,670
Alkalinity (mg/L)	none	4	<1	10	107	2	8	380
Dissolved solids residue 180 °C (mg/L)	500[b]	29	18	75	197	27	48	2,240
Dissolved oxygen (mg/L)	none	5	.1	2	7	.1	4	7
Major ions[a]								
Calcium (mg/L)	none	1	0.2	5.8	33	1.2	3.4	520
Magnesium (mg/L)	none	.2	.4	3	10	.3	1.4	9
Potassium (mg/L)	none	.1	.3	1.3	3	.2	1.4	2.8
Sodium (mg/L)	none	1.8	1.4	5.9	29	.9	4.6	228
Bromide (mg/L)	none	.02	< .01	.06	.36	< .01	*.03	1
Chloride (mg/L)	250[b]	2.1	2.1	8.1	68	1.3	6.8	120
Fluoride (mg/L)	2[b]	< .1	< .2	—	< .2	< .1	*.09	.9
Silica (mg/L)	none	15	8.3	18	33	8.2	14	42
Sulfate (mg/L)	250[b]	.7	.1	1.5	20	< .1	*.6	1,100
Iron (µg/L)	300[b]	<10	<10	—	10,200	<10	16	2,500
Manganese (µg/L)	50[b]	4.6	1.8	59	7,200	10	80	382
Nutrients								
Ammonia (mg/L) as N	none	< 0.04	< 0.04	—	3.1	< 0.02	*0.005	0.14
Ammonia plus organic (mg/L) as N	none	< .1	< .1	—	3.5	< .1	*.07	.15
Nitrite plus nitrate (mg/L) as N	10[c]	.30	< .05	3	17.6	< .05	*1.3	15
Phosphorus (mg/L) as P	none	< .006	< .006	—	.3	< .006	*.005	.2
Phosphorus, ortho (mg/L) as P	none	< .02	< .02	—	.2	< .01	*.002	.2
Dissolved organic carbon (mg/L) as C	none	E .2	< .33	.2	6	< .33	*.28	1.2

[a] Twenty-eight agricultural samples were analyzed for physical properties and major ions. One sample was filtered to remove flocculants that formed after sampling. No physical properties or major ion data are available for this sample.

[b] Secondary drinking-water standard, established by the U.S. Environmental Protection Agency.

[c] Maximum contaminant level for drinking water, established by the U.S. Environmental Protection Agency.

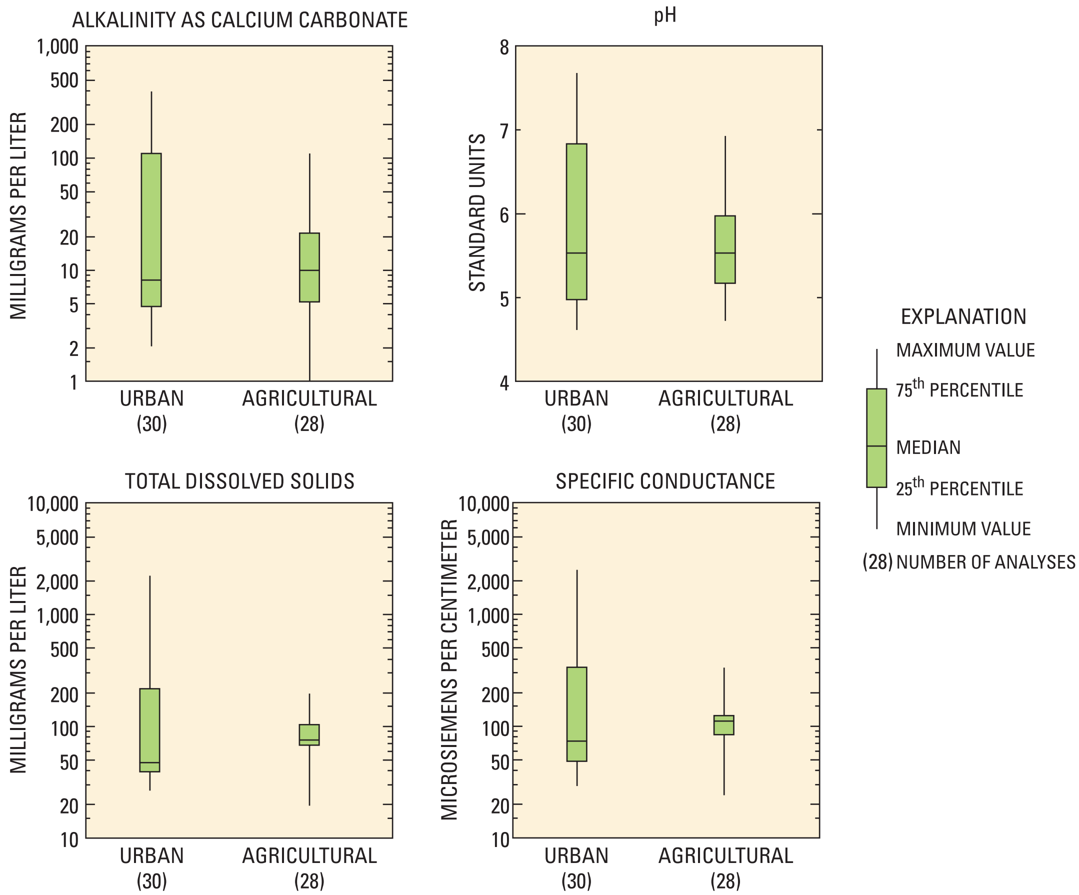


Figure 8. Concentrations of selected water-quality constituents in ground water collected from agricultural and urban wells in the Mobile River Basin.

with shallow ground water that has been recently recharged (Robinson, 2002).

Major Ions

Ground water collected from the agricultural wells typically had small concentrations of major ions, but a few samples had large concentrations of iron and manganese. The major ion composition of ground water collected from the reference well and the agricultural wells is illustrated in a Piper diagram (fig. 9).

The major ion content of water collected from the reference well plots near the lower right center of the cation and anion triangles, indicating water slightly more influenced by sodium, potassium, chloride, and nitrite-plus-nitrate ions (table 7; fig. 9). The major ion content of ground water from the agricultural wells plots near the center of the cation triangle, indicating no dominant cation; however, the major ion content is clustered near the lower right corner of the anion triangle, indicating water quality dominated by chloride and nitrite plus nitrate. A subset of six ground-water samples plot near the lower left corner of the anion triangle, indicating water quality dominated by carbonate and bicarbonate anions. Four of these samples were collected from wells completed in the Eutaw Formation, and two of the samples were collected from wells completed in the alluvial deposits. The distinct separation of the agricultural wells from the reference well on the Piper plot indicates either a different source for the water (alluvial and terrace deposits compared to the Eutaw Formation) or a change in water quality, possibly as a result of different land uses, or both.

Comparison of agricultural and urban ground-water quality indicated that ground water collected from agricultural wells had approximately equal or slightly greater median values for major ions, but typically had a smaller range of values compared to

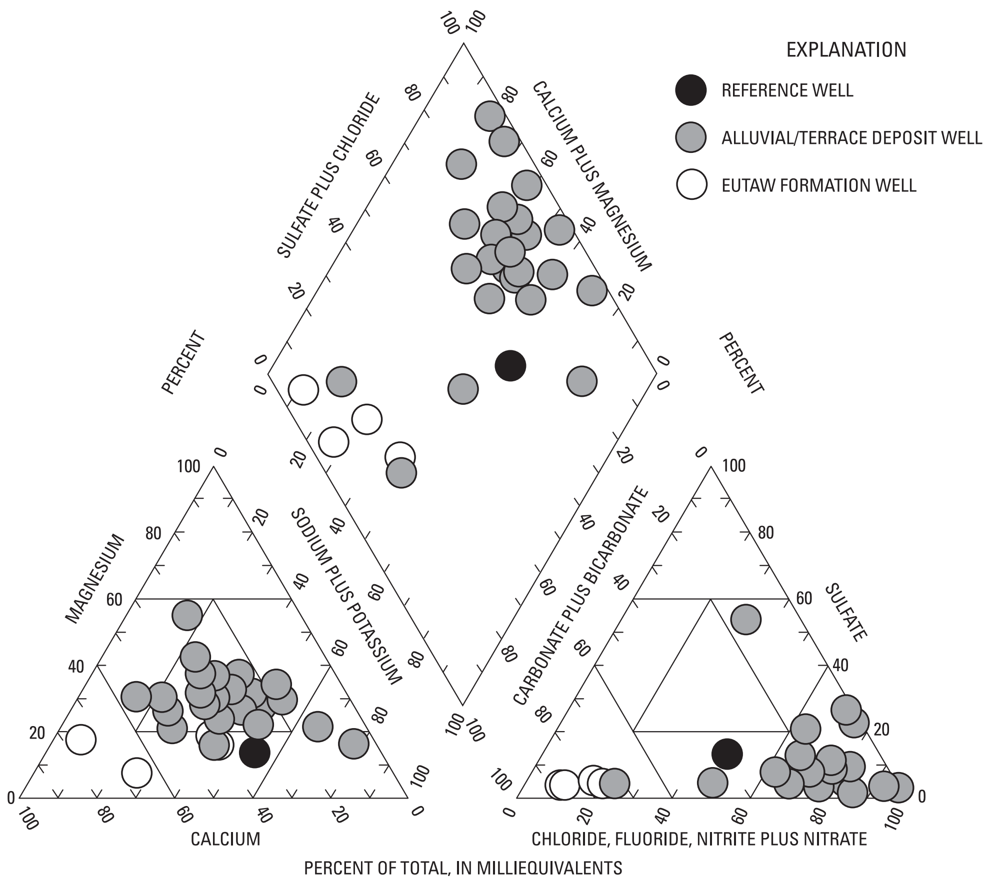


Figure 9. Piper trilinear diagram showing major ion composition of ground water collected from agricultural wells and the reference well.

ground water collected from the urban wells (table 7). The exceptions were the ranges in concentrations of iron, manganese, and potassium, which were greater in the samples collected from the agricultural wells. The median concentration of magnesium was greater in ground water collected from the agricultural wells than in ground water collected from the urban wells (fig. 10). The Wilcoxon rank-sum test indicated that magnesium was the only major ion present at statistically different concentrations in the two data sets.

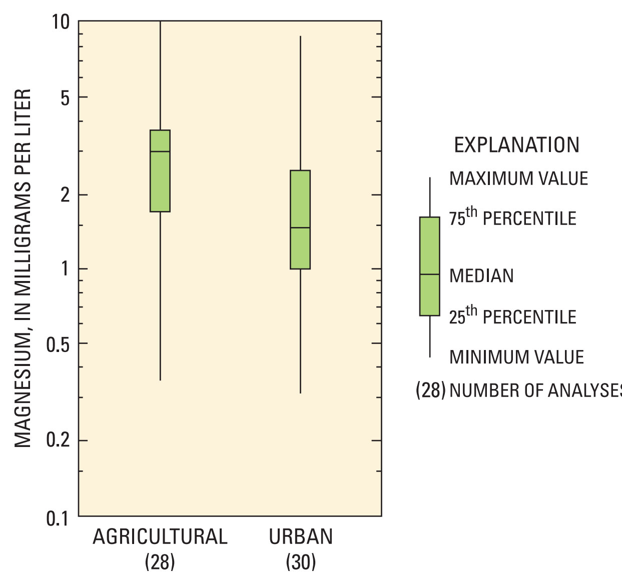


Figure 10. Concentrations of magnesium in ground water collected from agricultural and urban wells in the Mobile River Basin.

Nutrients and Dissolved Organic Carbon

Some of the ground-water samples collected from the agricultural wells contained greater concentrations of nutrients than typically found in ground water. Ammonia concentrations in ground water generally are less than 0.1 milligram per liter (mg/L; Mueller and Helsel, 1996); however, five agricultural ground-water samples contained ammonia concentrations ranging from 0.16 to 3.5 mg/L. Total nitrate concentrations in ground water generally are less than 2 mg/L (Mueller and Helsel, 1996); however, 19 agricultural ground-water samples contained nitrite-plus-nitrate concentrations ranging from 2.6 to 17.6 mg/L. Ground-water samples from two agricultural wells and one urban well contained nitrite-plus-nitrate concentrations that exceeded the U.S. Environmental Protection Agency's drinking-water maximum contaminant level of 10 mg/L. Phosphorus and orthophosphate concentrations generally are less than 0.1 and 0.02 mg/L, respectively (Mueller and Helsel, 1996), but six agricultural ground-water samples contained phosphorus or orthophosphate concentrations greater than these values. Most ground water contains dissolved organic carbon at concentrations less than 0.7 mg/L (James Kingsbury, U.S. Geological Survey, oral commun., 2002), but three agricultural ground-water samples contained dissolved organic carbon concentrations ranging from 1.1 to 6 mg/L.

Samples of ground water collected from the agricultural wells typically had a greater range of values and equal or slightly greater median values for nutrients than ground water collected from urban wells. The median value of nitrite plus nitrate (table 7; fig. 11) in the agricultural ground water was more than twice the median value in the urban ground water; however, the range of values was similar. The Wilcoxon rank-sum test indicated no statistically significant difference in nutrient concentrations between the urban and agricultural ground water.

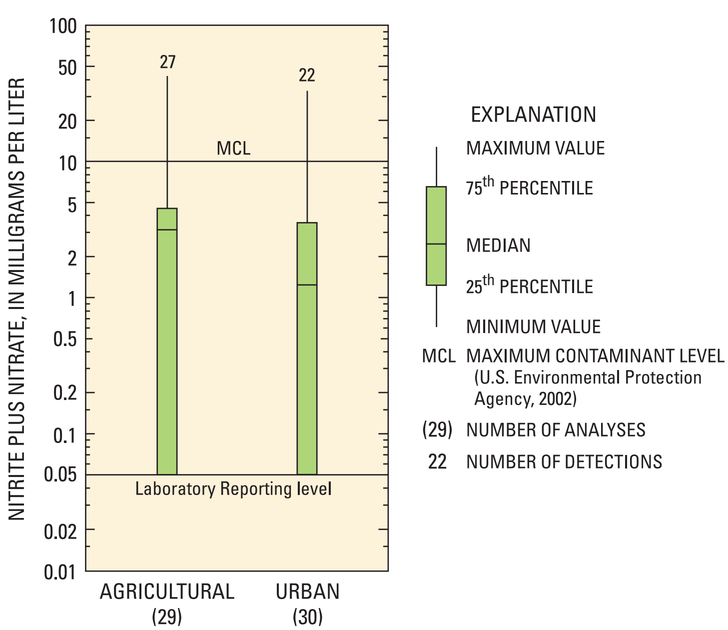


Figure 11. Concentrations of nitrite plus nitrate in ground water collected from agricultural and urban wells in the Mobile River Basin.

Pesticides

Ground water collected from the agricultural and urban wells was analyzed for 109 different pesticides and pesticide degradation products. Pesticides were detected in ground water collected from 25 of the 29 agricultural wells. Nineteen different pesticide compounds were detected a total of 83 times. The most frequently detected compounds, in order, were fluometuron, deethylatrazine, norflurazon, atrazine, aldicarb sulfoxide, aldicarb sulfone, diuron, and metolachlor. Herbicides and their degradation products were the most frequently detected class of pesticides (table 8; fig. 12). The range and distribution of concentrations of selected pesticides are shown in figure 13; many of the concentrations are similar, however, and do not appear as individual points on the graph when plotted. The greatest concentration of any pesticide was an estimated value of 1.4 microgram per liter (μg/L) of fluometuron (fig. 13; table 8).

Pesticide data for the agricultural and urban areas were censored to a common threshold so that detection frequencies between the two study areas could be compared (table 9). Pesticides were detected in a lesser percentage of the agricultural ground-water samples (14 of 29 wells) than in the urban ground-water samples (16 of 30 wells). Fewer total pesticides were detected in agricultural ground water than in urban ground water (26 and 44 detections, respectively), and fewer compounds were detected in agricultural ground water than in urban ground water (12 and 14 compounds, respectively). Atrazine was the only compound detected frequently enough in both agricultural and urban ground water to allow statistical testing. Results of the Wilcoxon rank-sum test indicated no statistically significant difference in atrazine concentrations in ground water collected from the agricultural and urban wells.

Age of Ground Water

Ground water collected from eight agricultural wells was analyzed for the environmental tracers CFCs and SF_6. Ground-water age is estimated by relating the measured concentration of the environmental tracer in the ground water to the reconstructed historical

Table 8. Maximum concentrations of selected pesticides in ground water collected from agricultural wells in the Mobile River Basin

[µg/L, microgram per liter; H, herbicide; I, insecticide; E, concentration less than the laboratory reporting level but greater than the long-term method detection level]

Pesticide	Type	Drinking-water guidelines	Agricultural wells (29 samples)	
			Frequency of detection (percent)	Maximum value
[a] Fluometuron (µg/L)	H	[b]90	58.6	E 1.4
Deethylatrazine (µg/L)	H	none	34.5	E .06
[a] Norflurazon (µg/L)	H	none	24.1	E .4
Atrazine (µg/L)	H	[c]3	24.1	.15
[a] Aldicarb sulfoxide (µg/L)	I	[d]4	24.1	E .06
[a] Aldicarb sulfone (µg/L)	I	[d]4	17.2	E .14
[a] Deisopropyl atrazine (µg/L)	H	none	13.8	E .08
[a] Diuron (µg/L)	H	[b]10	13.8	.04
[a] Hydroxy atrazine (µg/L)	H	none	13.8	E .13
Metolachlor (µg/L)	H	[b]70	13.8	.16
[a] Deethyl deisopropyl atrazine (µg/L)	H	none	10.3	E .008

[a] Constituent analyzed using NWQL Schedule 2060 procedure; results of analyses may be conservative.
[b] Human health guideline established by the U.S. Environmental Protection Agency, 2000.
[c] Maximum contaminant level for drinking water established by the U.S. Environmental Protection Agency, 2000.
[d] Draft maximum contaminant level for drinking water established by the U.S. Environmental Protection Agency, 2000.

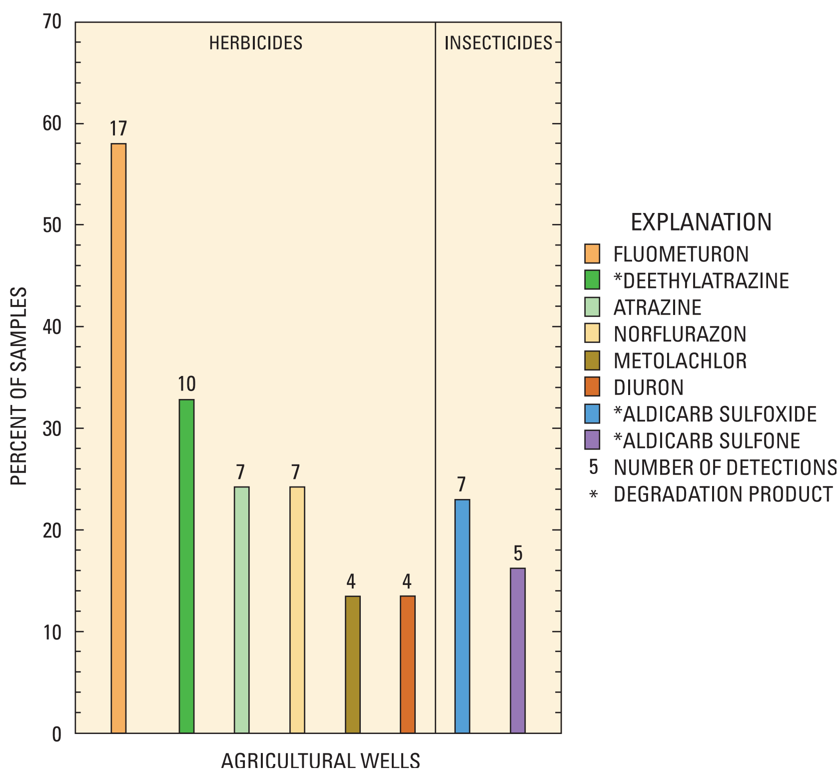


Figure 12. Detection frequencies of selected pesticides in ground water collected from agricultural wells in the Mobile River Basin.

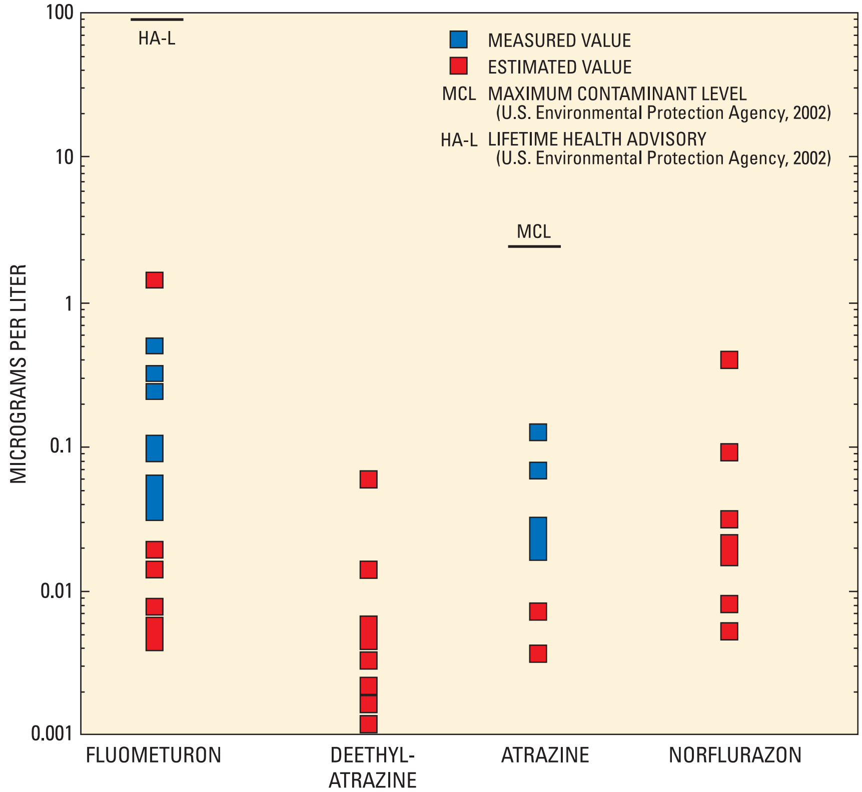


Figure 13. Range and distribution of concentrations of selected pesticides in ground water collected from agricultural wells in the Mobile River Basin.

Table 9. Detection frequencies of selected pesticides in ground water from agricultural and urban wells collected using common laboratory reporting levels

[LRL, laboratory reporting level; µg/L, microgram per liter; H, herbicide; I, insecticide]

Pesticide	Type	Agricultural wells: Frequency of detection (percent)	Urban wells: Frequency of detection (percent)	Common LRL (µg/L)
[a] Fluometuron	H	20.7	3.3	0.0617
Atrazine	H	17.2	20.0	.007
Deethylatrazine	H	6.9	33.3	.006
[a] Aldicarb sulfoxide	I	10.3	.0	.027
[a] Norflurazon	H	6.9	.0	.0774
Metolachlor	H	6.9	.0	.013
[a] Deisopropyl atrazine	H	3.4	3.3	.0737
[a] Deethyl deisopropyl atrazine	H	.0	10.0	.0599

[a] Constituent analyzed using NWQL Lab Code 9060 or Schedule 2060 procedure; results of analyses may be conservative.

atmospheric concentration and(or) calculated concentrations expected in water in equilibrium with air (Busenberg and Plummer, 1992, 2000). The estimated age of the water refers to the date of the introduction of chemicals to the water, which is assumed to be from the atmosphere and prior to the water entering the aquifer. Environmental processes, such as microbial degradation, sorption, and excess dissolved gasses, may affect the concentration of environmental tracers in the water.

Chlorofluorocarbons (CFCs) are synthetic compounds first produced in the early 1930's (Cook and Herczeg, 2000). The presence of measurable concentrations of CFCs in a water sample indicates that the sample contains some post-1940 water. Ground water collected from the agricultural land-use study wells was analyzed for CFC-11 (trichlorofluoromethane or $CFCl_3$), CFC-12 (dichlorodifluoromethane or CF_2Cl_2), and CFC-113 (trichlorotrifluoroethane or $C_2F_3Cl_3$). Sulfur hexafluoride (SF_6) is a trace atmospheric gas that occurs naturally in some minerals, igneous rocks, and in volcanic and igneous fluids; however, SF_6 is primarily of anthropogenic origin. Large-scale production of SF_6 began in the 1960's, and dating is possible from about 1970 (Busenberg and Plummer, 1997).

Ground water sampled from the agricultural wells ranged in age from about 14 to about 34 years, with a median age of about 18.5 years (table 10). The ages estimated for the ground water are consistent with the geology and hydrology of the study area and the design of the wells. The median age of the agricultural ground water is only slightly greater than the median age of the urban ground water collected from beneath eastern Montgomery, Alabama (table 10).

RELATIONS AMONG GROUND-WATER QUALITY, GROUND-WATER AGE, AND LAND USE

Results of applying the Spearman rho and Kendall tau correlation tests to determine statistically significant covariance among ground-water quality, ground-water age, and land use are provided in table 11. The tests are based on ranks. Concentrations of water-quality constituents less than the reporting level were assigned a value of one-half the smallest reported concentration to ensure that their rank was not equal to the rank of a measured value at or near the reporting level.

Some of the correlations listed in table 11 reflect the natural geochemical evolution of ground water as it ages. The pH, alkalinity, and concentration of iron in agricultural ground water increased as ground-water age increased. The concentration of dissolved oxygen and nitrite plus nitrate decreased as ground-water age increased. These correlations reflect common changes in ground-water quality that occur with time (Robinson, 2002) and support the accuracy of the ground-water age estimates in the agricultural land-use area.

A Piper diagram was constructed to illustrate the change in major ion composition of ground water as it ages (fig. 14). As ground-water age increases, the major ion composition moves away from magnesium-calcium and nitrite-plus-nitrate-dominated water quality to a more mixed composition. Water flowing through the subsurface and away from the original sources of magnesium and nitrite plus nitrate (land applications) dissolves minerals from the aquifer matrix and places ions from those minerals in solution. In addition, nitrates may be removed from solution by natural processes such as denitrification. These processes

Table 10. Depths to well screens and ages of ground water collected from agricultural and urban wells in the Mobile River Basin

[~, approximately; >, greater than]

Study area	Depths to well screens, in feet			[a]Ground-water age, in years		
	Minimum	Median	Maximum	Minimum	Median	Maximum
Agricultural (29 wells)	11	22.5	46	14	18.5	34
Urban (30 wells)	8	29	88	~ 1	12	> 45

[a] Age of ground water was determined for 30 urban samples and 8 agricultural samples.

Table 11. Correlation coefficients for selected physical properties and constituents in ground water collected from agricultural wells in the Mobile River Basin

[<, less than]

Variables	Number of sample pairs	Correlation coefficient	Probability statistic
[a] Ground-water age and pH	8	0.71	0.01
[a] Ground-water age and alkalinity	8	.64	.026
[a] Ground-water age and concentration of dissolved oxygen	8	- .57	.048
[a] Ground-water age and concentration of nitrite plus nitrate	8	- .91	.002
[a] Ground-water age and concentration of iron	8	.88	.003
[b] Concentrations of dissolved oxygen and nitrite plus nitrate	29	.81	< .001
[b] Concentrations of magnesium and nitrite plus nitrate	28	.58	.001
[b] Concentrations of nitrite plus nitrate and number of pesticides detected	29	.44	.018

[a] Kendall tau rank correlation test.

[b] Spearman rho rank correlation test.

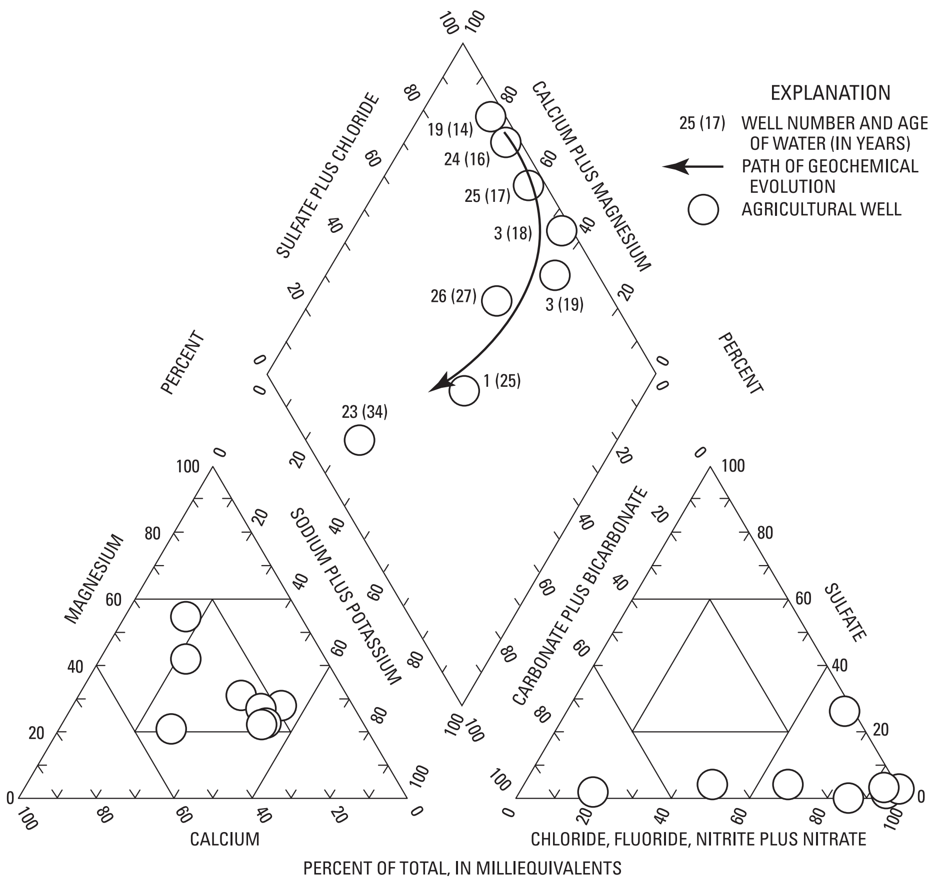


Figure 14. Piper trilinear diagram showing major ion composition and age of selected ground water collected from agricultural wells.

change the composition of the water, and the resulting ionic composition plots closer to the center of the Piper diagram. A similar pattern was found for urban ground water (Robinson, 2002).

Some correlations listed in table 11 may reflect the influence of agricultural practices on ground-water quality. The concentration of nitrite plus nitrate in agricultural ground water increased as the concentration of magnesium and the number of pesticides detected increased. This correlation likely reflects the application of pesticides, nitrogen-based fertilizer, and crushed limestone and dolomite containing magnesium.

Land use was associated with the distribution and occurrence of pesticides in ground water. The herbicides fluometuron, norflurazon, metolachlor, and diuron were found only in ground water collected from the agricultural area, except for one detection of fluometuron in an urban sample collected near a cotton field. Aldicarb, or its degradation products, was found only in the agricultural area. Dieldrin, simazine, and terbacil were detected only in urban ground water (Robinson, 2002). Atrazine and deethylatrazine were found in ground water beneath both agricultural and urban areas.

No correlation was found between crop type and ground-water quality in the agricultural area. The lack of correlation may be due to agricultural practices, such as crop rotation and the cultivation of a variety of crops. The lack of correlation also could indicate that the recharge area of the ground water was not influenced by row cropping; however, ground water probably does not flow long distances from the recharge area because the shallow sediments occur as lenses of limited geographic extent.

SUMMARY

Ground-water quality in a shallow aquifer and the underlying Black Warrior River aquifer was evaluated beneath an agricultural area and compared to ground-water quality in the same aquifers beneath an urban area. The agricultural and urban areas are located in the flood plains of the Alabama, Black Warrior, Coosa, and Tallapoosa Rivers and their tributaries in central Alabama. Row cropping has been practiced in some of the fields where the agricultural wells were drilled for nearly 100 years. Major crops grown in these flood plains include cotton, corn, and beans. Crop rotation and no-till planting are practiced, and a variety of crops are grown on about one-third of the farms. The urban wells were drilled in a residential and commercial area of eastern Montgomery, Alabama, where development began about 1965 and continued in some areas through 1995.

All of the wells sampled either produce water from the shallow aquifer that overlies and recharges the Black Warrior River aquifer or from the uppermost unit of the Black Warrior River aquifer. Ground water was collected from 29 wells located in the agricultural area and from 30 wells located in the urban area. The wells were completed in the same geologic units and have approximately the same range and median values of depth; the age range of ground water collected from the wells was similar. Statistically significant differences in water quality between the two sample sets could reasonably be attributed to differences in land use. Ground-water samples were analyzed for physical properties, major ions, nutrients, pesticides, chlorofluorocarbons, sulfur hexafluoride, and dissolved gases.

There were no statistical differences in the median concentrations of most major ions and nutrients in ground water collected from beneath the agricultural and the urban areas. The median concentration of magnesium, however, was statistically greater in the agricultural ground water. The greater median concentration of magnesium in the agricultural ground water is attributed to applications of crushed limestone and dolomite, containing magnesium, that are used to moderate the pH of the acidic soils. Concentrations of ammonia, nitrite plus nitrate, phosphorus and orthophosphate, and dissolved organic carbon in ground water collected from many of the agricultural wells were greater than concentrations typically found in ground water, but not statistically greater than the concentrations measured in ground water collected from the urban wells.

Pesticides were detected in a lesser percentage of agricultural ground-water samples than in urban ground-water samples, and the total number of pesticide detections was greater in the urban ground water. The number of pesticide compounds detected in urban ground water also was greater than in agricultural ground water. The results of the Wilcoxon rank-sum test indicated no statistical difference in concentrations of atrazine between samples of agricultural and urban ground water.

The Spearman rho and Kendall tau tests were used to check for statistically significant covariance between agricultural ground-water quality, ground-water age, and land use. The pH, alkalinity, and concentration of iron in agricultural ground water increased as ground-water age increased. The concentration of nitrite plus nitrate decreased as ground-water age increased and as the concentration of dissolved oxygen decreased. These correlations possibly indicate the consumption of nitrogen-based compounds by natural processes such as denitrification. The concentration of nitrite plus nitrate increased as the concentration of magnesium and the numbers of pesticide detections increased. These correlations are attributed to land application of nitrogen-based fertilizer, crushed limestone and dolomite containing magnesium, and pesticides. No correlation was found between water quality and land use or crop type, probably as a result of agricultural practices, such as crop rotation and the cultivation of a variety of crops.

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APPENDIX

NWQL SCHEDULE 2060

The NWQL Lab Code 9060 was an experimental method until approved as the Schedule 2060 analytical method in August 2001. The urban ground water samples collected during 1999 and 2000 were analyzed for the compounds listed on NWQL Lab Code 9060; but these data were not published in Robinson (2002) because the results of analyses using experimental methods are considered to be conditional. During the time before March 1, 2000, the holding times for some samples that were analyzed for the compounds listed in NWQL Lab Code 9060 exceeded the median half-life of some of the compounds. The median half-life for each compound was determined based on an analyses of matrix spike samples held for known time periods (Furlong and others, 2001). The results of analyses of the urban ground water for the compounds listed in Lab Code 9060 are included in this report (Appendix table 2). However, due to the low mean-recovery percentage for spiked samples and the large variance between results of replicate samples for NWQL Schedule 2060 (table 4), in addition to excessive holding times for some samples collected before March 1, 2000; the analyses for compounds listed in NWQL Lab Code 9060 are considered to be conservative.

Appendix table 1. List of chemical compounds and analytical methods for National Water Quality Laboratory Schedule 2060 (Lab Code 9060 prior to August 2001), high performance liquid chromatography/mass spectrometric - solid phase extraction

[CAS, chemical abstract service; NWQL, National Water Quality Laboratory]

Compound	CAS number	Minimum reporting level (μg/L)
2,4-D	94-75-7	0.021
2,4-D methyl ester	1928-38-7	0.0086
2,4-DB	94-82-6	0.016
2-Hydroxyatrazine	2163-68-0	0.008
3(4-Chlorophenyl)-1-methyl urea	5352-88-5	0.024
3-Hydroxycarbofuran	16655-82-6	0.0058
3-Ketocarbofuran	6709-30-1	1.5
Acifluorfen	50594-66-6	0.0066
Aldicarb	116-06-3	0.04
Aldicarb sulfone	1646-88-4	0.02
Aldicarb sulfoxide	1646-87-3	0.0082
Atrazine	1912-24-9	0.009
Bendiocarb	22781-23-3	0.025
Benomyl	17804-35-2	0.0038
Bensulfuron-methyl	83055-99-6	0.015
Bentazon	25057-89-0	0.011
Bromacil	314-40-9	0.033
Bromoxynil	1689-84-5	0.017
Caffeine	58-08-2	0.0096
Carbaryl	63-25-2	0.028
Carbofuran	1563-66-2	0.0056
Chloramben, methyl ester	7286-84-2	0.018
Chlorimuron-ethyl	90982-32-4	0.0096
Chlorothalonil	1897-45-6	0.035
Clopyralid	1702-17-6	0.013
Cycloate	134-23-2	0.013
Dacthal monoacid	887-54-7	0.011
Deethyl atrazine	6190-65-4	0.028
Deethyl deisopropyl atrazine	3397-62-4	0.01
Deisopropylatrazine	1007-28-9	0.044
Dicamba	1918-00-9	0.012
Dichlorprop	120-36-5	0.013
Dinoseb	88-85-7	0.012
Diphenamid	957-51-7	0.026
Diuron	330-54-1	0.015
Fenuron	101-42-8	0.031
Flumetsulam	98967-40-9	0.011
Fluometuron	2164-17-2	0.031
Imazaquin	81335-37-7	0.016
Imazethapyr	81335-77-5	0.017
Imidacloprid	138261-41-3	0.0068
Linuron	330-55-2	0.014
MCPA	94-74-6	0.016
MCPB	94-81-5	0.015
Metalaxyl	57837-19-1	0.02
Methiocarb	2032-65-7	0.008
Methomyl	16752-77-5	0.0044
Methomyl-oxime	13749-94-5	0.011
Metsulfuron methyl	74223-64-6	0.025
Neburon	555-37-3	0.012
Nicosulfuron	111991-09-4	0.013
Norflurazon	27314-13-2	0.016
Oryzalin	19044-88-3	0.017
Oxamyl	23135-22-0	0.012
Oxamyl-oxime	30558-43-1	0.013
Picloram	1918-02-1	0.019
Propham	122-42-9	0.0096
Propiconazole	60207-90-1	0.021
Propoxur	114-26-1	0.008
Siduron	1982-49-6	0.016
Sulfometuron-methyl	74222-97-2	0.0088
Tebuthiuron	34014-18-1	0.0062
Terbacil	5902-51-2	0.0098
Tribenuron-methyl	101200-48-0	0.0088
Triclopyr	55335-06-3	0.022

Sampling Requirements

Description: 1 liter glass bottle, amber
Treatment and preservation: Bottle baked at 450 degrees Celsius by laboratory. DO NOT RINSE BOTTLE. Do not fill bottle beyond shoulder, as reagents must be added to the sample at the NWQL before analyses. Chill sample and maintain at 4 degrees Celsius; ship immediately.

Appendix table 2. Results of analyses of urban ground water for constituents of NWQL Lab Code 9060

[µg/L, microgram per liter; <, less than; E, estimated value; M, presence verified but not quantified]

Well	2,4-D Methyl ester (µg/L)	2,4-D Dissolved (µg/L)	2,4-DB (µg/L)	3 Hydrxy carbofuran (µg/L)	3-Keto carbofurab (µg/L)	Acifluorfe (µg/L)	Aldicarb sulfone (µg/L)	Aldicarb sulfoxide (µg/L)	Aldicarb (µg/L)	Atrazine (µg/L)	Bendiocarb (µg/L)
LUSCR1-1	<0.09	<0.08	<0.05	<0.06	<0.07	<0.06	<0.2	<0.03	<0.08	0.553	<0.06
LUSRC1-2	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06
LUSRC1-3	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06
LUSRC1-4	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	.008	<.06
LUSRC1-5	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	.004	<.06
LUSRC1-6	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	E.003	<.06
LUSRC1-7	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.10	<.001	<.06
LUSRC1-8	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.10	E.002	<.06
LUSRC1-9	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06
LUSRC1-10	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.10	.011	<.06
LUSRC1-11	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	.123	<.06
LUSRC1-12	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06
LUSRC1-13	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06
LUSRC1-14	E.01	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06
LUSRC1-15	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.005	<.06
LUSRC1-16	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06
LUSRC1-17	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	.274	<.06
LUSRC1-18	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06
LUSRC1-19	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	E.002	<.06
LUSRC1-20	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.10	.048	<.06
LUSRC1-21	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06
LUSRC1-22	E.01	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06
LUSRC1-23	<.09	<.08	<.05	<.06	<.07	<.06	<.2	--	<.08	<.001	<.06
LUSRC1-24	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06
LUSRC1-25	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06
LUSRC1-26	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06
LUSRC1-27	E.01	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.001
LUSRC1-28	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06
LUSRC1-29	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06
LUSRC1-30	<.09	<.08	<.05	<.06	<.07	<.06	<.2	<.03	<.08	<.001	<.06

Appendix table 2. Results of analyses of urban ground water for constituents of NWQL Lab Code 9060—Continued

[µg/L, microgram per liter; <, less than; E, estimated value; M, presence verified but not quantified]

WELL	Benomyl (µg/L)	Bensulfuron methly (µg/L)	Bentazon (µg/L)	Bromacil (µg/L)	Bromoxynil (µg/L)	Cafeine (µg/L)	Carbaryl (µg/L)	Carbofuran (µg/L)	Chloramben, methyl ester (µg/L)	Chlorimuron (µg/L)	Chloro-thalonil (µg/L)
LUSCR1-1	<0.02	<0.05	<0.02	<0.08	<0.06	<0.08	<0.06	<0.06	<0.1	<0.04	<0.05
LUSRC1-2	<.02	<.05	<.02	--	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-3	<.02	<.05	<.02	E.02	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-4	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	E.27
LUSRC1-5	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-6	<.02	<.05	<.02	E.02	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-7	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-8	<.02	<.05	<.02	E.03	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-9	<.02	<.05	<.02	E.11	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-10	<.02	<.05	<.02	E.05	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-11	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-12	<.02	<.05	<.02	E.03	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-13	<.02	<.05	E.01	E.02	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-14	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-15	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-16	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-17	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-18	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-19	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-20	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-21	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-22	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-23	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-24	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-25	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-26	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-27	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-28	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-29	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05
LUSRC1-30	<.02	<.05	<.02	<.08	<.06	<.08	<.06	<.06	<.1	<.04	<.05

Appendix table 2. Results of analyses of urban ground water for constituents of NWQL Lab Code 9060—Continued

[µg/L, microgram per liter; <, less than; E, estimated value; M, presence verified but not quantified]

WELL	Clopyralid (µg/L)	Cycloate (µg/L)	Dacthal monoacid (µg/L)	Deethyl atrazine (µg/L)	Deethyl deisopropyl atrazine (µg/L)	Deisopropyl atrazine (µg/L)	Dicamba (µg/L)	Dichlor prop (µg/L)	Dinoseb (µg/L)	Diphenamid (µg/L)	Diuron (µg/L)
LUSCR1-1	<0.04	<0.05	<0.07	E0.112	E0.06	E0.02	<0.10	<0.05	<0.04	<0.06	<0.08
LUSRC1-2	<.04	--	<.07	<.002	--	--	<.10	<.05	<.04	--	<.08
LUSRC1-3	<.04	<.05	<.07	E.301	E.03	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-4	<.04	<.05	<.07	E.004	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-5	<.04	<.05	<.07	E.004	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-6	<.04	<.05	<.07	E.004	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-7	<.04	<.05	<.07	<.002	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-8	<.04	<.05	<.07	E.031	M	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-9	<.04	<.05	<.07	E.009	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-10	<.04	<.05	<.07	E.365	E.13	E.01	<.10	<.05	<.04	<.06	<.08
LUSRC1-11	<.04	<.05	<.07	E.074	E.06	E.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-12	<.04	<.05	<.07	E.206	E.04	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-13	<.04	<.05	<.07	E.024	E.01	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-14	<.04	<.05	<.07	<.002	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-15	<.04	<.05	<.07	<.002	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-16	<.04	<.05	<.07	<.002	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-17	<.04	<.05	<.07	E.112	.07	E.05	<.10	<.05	<.04	<.06	<.08
LUSRC1-18	<.04	<.05	<.07	<.002	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-19	<.04	<.05	<.07	E.003	E.01	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-20	<.04	<.05	<.07	E.045	E.09	E.11	<.10	<.05	<.04	<.06	<.08
LUSRC1-21	<.04	<.05	<.07	<.002	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-22	<.04	<.05	<.07	<.002	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-23	<.04	<.05	<.07	<.002	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-24	<.04	<.05	<.07	<.002	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-25	<.04	<.05	<.07	<.002	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-26	<.04	<.05	<.07	<.002	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-27	<.04	<.05	<.07	<.002	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-28	<.04	<.05	<.07	E.004	<.06	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-29	<.04	<.05	<.07	E.004	M	<.07	<.10	<.05	<.04	<.06	<.08
LUSRC1-30	<.04	<.05	<.07	<.002	<.06	<.07	<.10	<.05	<.04	<.06	<.08

Appendix table 2. Results of analyses of urban ground water for constituents of NWQL Lab Code 9060—Continued

[µg/L, microgram per liter; <, less than; E, estimated value; M, presence verified but not quantified]

WELL	Fenuron (µg/L)	Flumetsulam (µg/L)	Fluometuron (µg/L)	Hydroxy atrazine (µg/L)	Imazaquin (µg/L)	Imazethapyr (µg/L)	Imidacloprid (µg/L)	Linuron (µg/L)	MCPA (µg/L)	MCPB (µg/L)	Metalaxyl (µg/L)
LUSCR1-1	<0.07	<0.09	<0.06	E0.1	<0.1	<0.09	<0.1	<0.07	<0.06	<0.06	<0.06
LUSRC1-2	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-3	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-4	<.07	<.09	<.06	<.2	<.1	E.03	<.1	<.07	<.06	<.06	<.06
LUSRC1-5	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-6	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-7	<.07	<.09	<.06	<.2	<.1	--	<.1	<.07	<.06	<.06	<.06
LUSRC1-8	<.07	<.09	<.06	E.1	<.1	--	<.1	<.07	<.06	<.06	<.06
LUSRC1-9	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-10	<.07	<.09	.07	<.2	<.1	--	<.1	<.07	<.06	<.06	<.06
LUSRC1-11	<.07	<.09	<.06	M	<.1	<.09	.1	<.07	<.06	<.06	<.06
LUSRC1-12	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-13	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-14	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-15	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-16	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-17	<.07	<.09	<.06	E.1	M	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-18	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-19	<.07	<.09	<.06	<.2	<.1	--	<.1	<.07	<.06	<.06	<.06
LUSRC1-20	<.07	<.09	<.06	<.2	<.1	--	<.1	<.07	<.06	<.06	E.04
LUSRC1-21	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-22	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-23	<.07	<.09	<.06	<.2	<.1	--	<.1	<.07	<.06	<.06	<.06
LUSRC1-24	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-25	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-26	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-27	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-28	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06
LUSRC1-29	<.07	<.09	<.06	<.2	<.1	--	<.1	<.07	<.06	<.06	<.06
LUSRC1-30	<.07	<.09	<.06	<.2	<.1	<.09	<.1	<.07	<.06	<.06	<.06

Appendix table 2. Results of analyses of urban ground water for constituents of NWQL Lab Code 9060—Continued

[µg/L, microgram per liter; <, less than; E, estimated value; M, presence verified but not quantified]

WELL	Methiocarb (µg/L)	Methomyl oxime (µg/L)	Methomyl (µg/L)	Metsulfuron methyl (µg/L)	Neburon (µg/L)	Nico sulfuron (µg/L)	Norflurazon (µg/L)	Oryzalin (µg/L)	Oxamyl oxime (µg/L)	Oxamyl (µg/L)	Picloram (µg/L)
LUSCR1-1	<0.08	<0.01	<0.08	<0.1	<0.07	<0.07	<0.08	<0.07	<0.06	<0.02	<0.07
LUSRC1-2	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-3	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-4	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-5	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-6	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-7	<.08	<.20	<.08	<.2	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-8	<.08	<.20	<.08	<.2	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-9	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-10	<.08	<.20	<.08	<.2	<.07	<.07	E.02	<.07	<.06	<.02	<.07
LUSRC1-11	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-12	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-13	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-14	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-15	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-16	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-17	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-18	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-19	<.08	<.20	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-20	<.08	<.20	<.08	<.2	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-21	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-22	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-23	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-24	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-25	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-26	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-27	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-28	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-29	<.08	<.20	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07
LUSRC1-30	<.08	<.01	<.08	<.1	<.07	<.07	<.08	<.07	<.06	<.02	<.07

Appendix table 2. Results of analyses of urban ground water for constituents of NWQL Lab Code 9060—Continued

[μg/L, microgram per liter; <, less than; E, estimated value; M, presence verified but not quantified]

WELL	Propham (μg/L)	Pro piconazole (μg/L)	Propoxur (μg/L)	Siduron (μg/L)	Sulfo metruron methyl (μg/L)	Tebuthiuron (μg/L)	Terbacil (μg/L)	Tribenuron methyl (μg/L)	Triclopyr (μg/L)	Urea (4-chloro-phenyl-1-methyl) (μg/L)
LUSCR1-1	<0.07	<0.06	<0.06	<0.09	<0.04	<0.01	<0.10	<0.07	<0.1	<0.09
LUSRC1-2	<.07	<.06	<.06	<.09	<.04	<.01	--	<.07	<.1	<.09
LUSRC1-3	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-4	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-5	<.07	<.06	<.06	<.09	<.04	<.01	E.03	<.07	<.1	<.09
LUSRC1-6	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-7	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-8	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-9	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-10	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-11	<.07	<.06	<.06	<.09	<.04	M	<.10	<.07	<.1	<.09
LUSRC1-12	<.07	<.06	E.04	<.09	M	<.01	<.10	<.07	<.1	<.09
LUSRC1-13	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-14	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-15	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-16	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-17	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-18	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-19	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-20	M	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-21	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-22	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-23	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-24	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-25	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-26	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-27	<.07	<.06	<.06	<.09	<.04	<.01	E.02	<.07	<.1	<.09
LUSRC1-28	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-29	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09
LUSRC1-30	<.07	<.06	<.06	<.09	<.04	<.01	<.10	<.07	<.1	<.09