Ground-Water-Quality Assessment of Shallow Aquifers in the Front Range Urban Corridor, Colorado, 1954–98

By Jennifer L. Flynn

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Abstract

Historical (1954–98) water-quality data for major ions, trace elements, major plant nutrients, and organic constituents collected in 3,870 sampling events at 2,138 shallow wells represent ground-water quality in shallow aquifers that underlie the Front Range Urban Corridor in Colorado. Nonparametric summary statistics and maps of concentrations across the study area indicate that ground water in the study area included fresh to saline water. Sulfate concentrations were elevated in the north and northeast parts of the study area, possibly due to Pierre Shale and Laramie Formation shale outcrops in those areas. Apart from isolated areas of known contamination, chloride concentrations were generally less than 100 milligrams per liter across the study area. Wells with elevated nitrate concentrations usually were located near rivers and streams downgradient from metropolitan areas. Elevated nitrate concentrations in wells that were not along the South Platte River were possibly from individual sewage disposal system usage or from fertilizer application to land. Spatial distribution for organic compounds for which more than 40 percent of the data were above the detection limit (atrazine, methyl-*tert*-butylether, and prometon) is not widespread across the study area, but this may reflect limitations of data availability.

Summary statistics calculated or estimated by decade are influenced by the temporal variability of data across the study area. The median values of specific conductance, chloride, and nitrate from the 1970’s are less than values from the 1980’s and 1990’s, which, because most samples from the l970’s were collected in the western part of the study area, indicates that water quality in the western part of the study area is generally different than the rest of the study area. Chloride may be introduced to ground water from runoff of road deicers or chlorinated organics in transportation/transitional areas, where the median concentration is the greatest (85.0 milligrams per liter). Nitrate median concentrations are several times greater where the land is cultivated or used for agricultural business, which may reflect use of nitrogen fertilizers and the presence of animal feeding operations.

Most inorganic and organic constituents exceeded drinking-water standards in only a small percentage of samples. Exceptions to this include sulfate; nitrate; trace elements aluminum, cadmium, iron, and manganese; and organic compounds 1,1-dichloroethylene, tetrachloroethylene, trichloroethylene, benzene, and dichloromethane.

INTRODUCTION

The Front Range Infrastructure Resources Project (FRIRP) was a multidisciplinary effort by the U.S. Geological Survey (USGS) to evaluate the natural resources in the Front Range Urban Corridor in Colorado (fig. 1) that are necessary for development of infrastructure (roads, airports, water and energy transmission and distribution facilities, sewage treatment

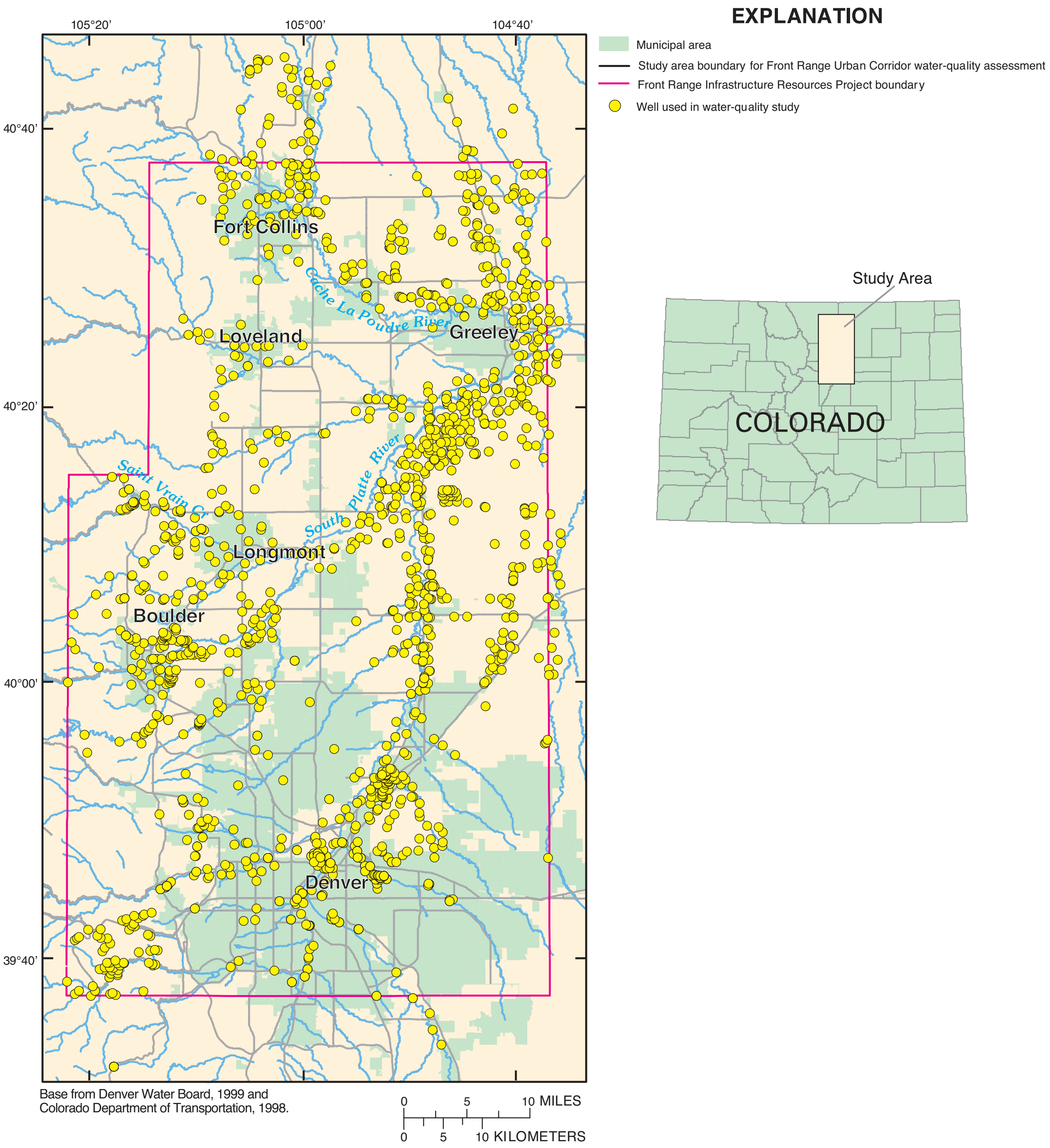


Figure 1. Locations of the study area and water-quality wells in the Front Range Urban Corridor, Colorado.

plants, and many other facilities). Infrastructure is critical to sustain any populated area. New infrastructure must be constructed to meet increasing needs in areas of rapid population growth. Rehabilitation of existing infrastructure and development of new infrastructure require three natural resources: natural aggregate (stone, sand, and gravel), water, and energy. The FRIRP evaluated natural aggregate, energy, biological, land, and water resources in the Front Range Urban Corridor.

Ground water is an infrastructure resource present in shallow aquifers and deeper bedrock aquifers that underlie the Front Range Urban Corridor. Water in the aquifers is derived primarily from infiltration of precipitation, leakage from streams, canals, and ponds, and infiltration of irrigation water applied to lawns, gardens, and commercial crops. Natural and anthropogenic constituents can infiltrate from land surface as water percolates into aquifers (Fetter, 1999). Moderately to very permeable soils and shallow depth to water enable rapid recharge of the aquifer as well as a potential link to surface contamination sources. The alluvial aquifer beneath Denver is vulnerable to contamination that can affect the quality of the ground-water resource because of its shallow water table and high permeability of overlying materials. Because quality of ground water may be related to its suitability for use, it is useful to examine the current status of water quality in the shallow aquifers of the Front Range Urban Corridor.

Purpose and Scope

This report describes historical (1954–98) water-quality data from shallow ground water within the Front Range Urban Corridor. Information from 2,138 wells located in shallow aquifers of the 2,450-square-mile study area is used to examine concentrations of major ions, trace elements, major plant nutrients, and organic constituents. This work was done in cooperation with the Colorado Department of Natural Resources, Division of Water Resources, and the Colorado Water Conservation Board.

Acknowledgments

Thanks to David Rogers and Bill Crick of the Colorado Department of Public Health and Environment for providing water-quality data for this study. The author also thanks Janet Heiny, Sharon Johnson, Rick Arnold, Kip Bossong, Doug Druliner, and James LaBaugh of the USGS.

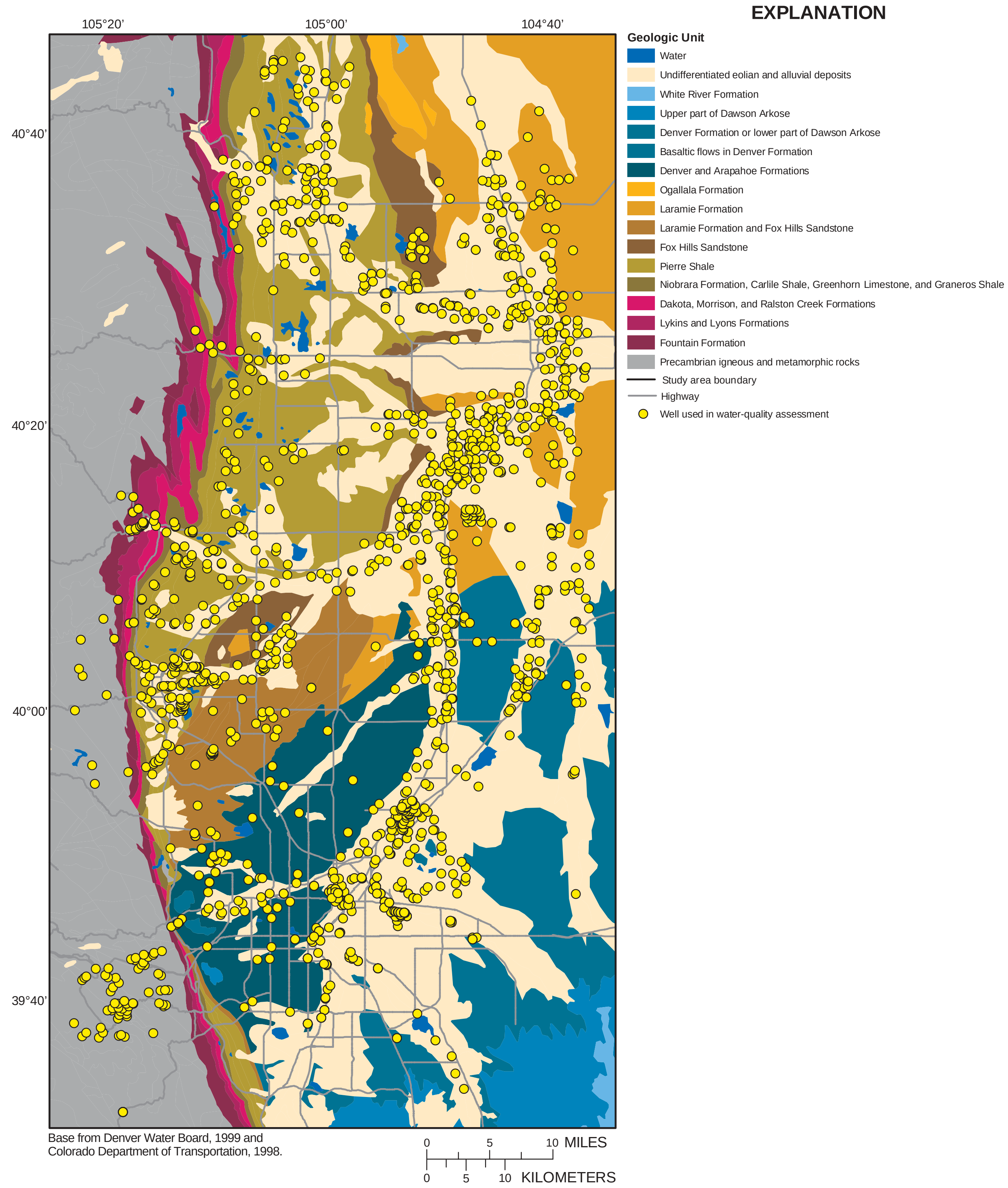
DESCRIPTION OF THE FRONT RANGE URBAN CORRIDOR

The study area for the water-quality assessment is located along the eastern edge of the Front Range of the Rocky Mountains in Colorado (fig. 1). The study area encompasses the northern front range urban corridor from just south of the Denver metropolitan area to just north of Fort Collins, and from the foothills of the Rocky Mountains in the west to just east of Greeley, Colo.

Hydrogeologic Setting

Sedimentary strata of sandstone, shale, siltstone, conglomerate, and limestone, which are Paleozoic to Tertiary in age, overlie Precambrian crystalline rock in the study area (Knepper, 2002) (fig. 2). Mountain-building events starting about 70 million years ago have uplifted the Precambrian rocks to what is now the Colorado Front Range. The sedimentary strata were also uplifted, and the layers close to the mountains are nearly vertical; rocks a few miles east of the mountains were only slightly deformed and dip gradually to the east. East of Denver (14 miles from the mountains), the rocks dip gradually to the west. The bowl-shaped dip of the rocks in the subsurface defines the Denver Basin (Robson, 1987; Robson and Romero, 1981) (fig. 3).

Four principal bedrock aquifers underlie the study area (Robson and others, 1998). The Laramie-Fox Hills aquifer (Cretaceous) is the deepest of these and consists of the Laramie Formation, Fox Hills Sandstone, and upper Pierre Shale Formation. Overlying the Laramie-Fox Hills aquifer are the Arapahoe (Cretaceous), Denver (Cretaceous-Tertiary), and Dawson (Tertiary) aquifers. These bedrock aquifers are recharged in outcrop areas along the eastern front of the Rocky Mountains.



Base from Denver Water Board, 1999 and
Colorado Department of Transportation, 1998.

Figure 2. Geologic map of study area.

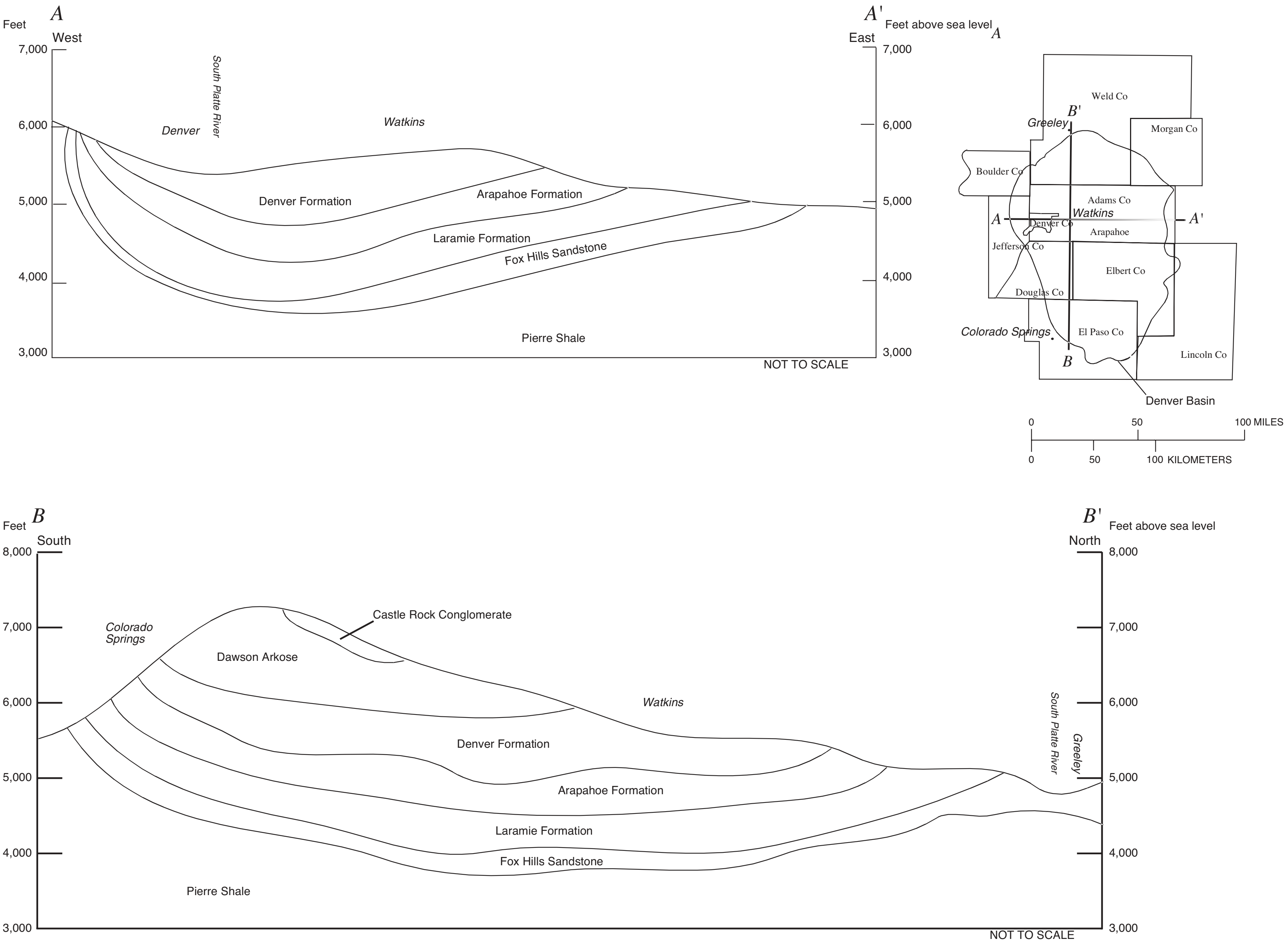


Figure 3. Generalized geologic section of the Denver Basin.

Shallow alluvial aquifers underlie large parts of the study area and are productive sources of ground water in the principal stream valleys (Robson, 1996; Robson, Arnold, and Heiny, 2000a, 2000b; Robson, Heiny, and Arnold, 2000a, 2000b). These aquifers consist of layers of silt, sand, and gravel that commonly are less than 30 feet thick in upland areas between stream valleys. In the principal stream valleys, the layers of silt, sand, and gravel range in thickness from 40 to 120 feet.

The surface of the bedrock beneath the shallow alluvial aquifers has been eroded into a series of valleys and intervening hills (Robson, 1996; Robson, Arnold, and Heiny 2000a, 2000b; Robson, Heiny, and Arnold, 2000a, 2000b). Most valleys in the bedrock surface correspond with current stream valleys; however, some were carved long ago by streams that no longer flow (paleovalleys). Many of these paleovalleys have been filled with windblown silt and sand or waterborne sand and gravel. Some paleovalleys are not easily seen on the present land surface but can be identified through well logs. Sediment thickness in paleovalleys can range from 20 to more than 100 feet (Robson, 1996).

Water Use

Most of the water used in the study area at the present time (2002) is surface water (71 percent). The 29 percent of the water that comes from ground water is drawn primarily from the alluvial aquifers and is used mostly for irrigation (71 percent), power generation (15 percent), and domestic use (8 percent) (Dennehy and others, 1995). About 40 percent of the domestic ground-water use is for household lawn and garden irrigation along the Front Range Urban Corridor (Litke and Appel, 1989).

Land Use

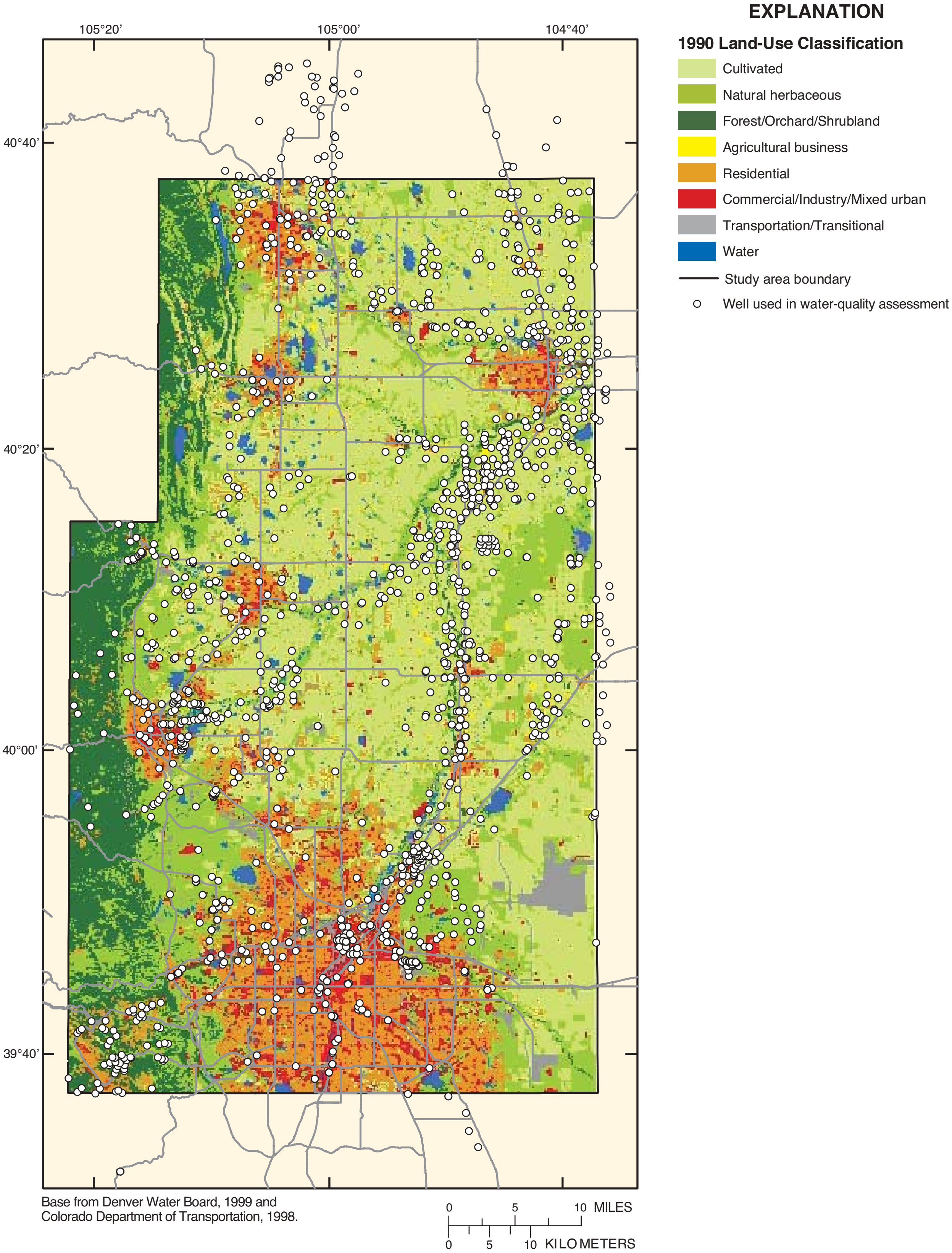
Land-use classifications were assigned to the FRIRP study area as part of the FRIRP land-use study (U.S. Geological Survey, 1999). For this report, the classifications for 1990 were combined into eight categories: cultivated, natural herbaceous, forest/orchard/shrubland, agricultural business, residential, commercial/industry/mixed urban, transportation/transitional, and water (fig. 4).

The dominant land-use classification is cultivated land (areas of herbaceous vegetation planted and(or) cultivated by humans for the production of food, feed, fiber, pasture, or seed), which accounts for 40.5 percent of the FRIRP study area. Natural herbaceous land accounts for 21.4 percent of the area, forest and shrubland for 11.2 percent. Agricultural business, which includes fish hatcheries, feedlots, poultry farms, dairy farms, temporary shipping and holding pens, animal breeding or training facilities, greenhouses, and confined animal feeding operations, covers only 0.8 percent of the study area but can have an important effect on ground-water quality.

Residential areas account for 13.4 percent of the total land use in the area, mostly in urban areas. Commercial, industrial, and mixed urban account for 6.2 percent of land use in the area. The variety and intensity of urban activities can have a disproportionate effect on water quality even though this land use accounts for only 19.6 percent of all land in the study area. Transportation (roads, airports, and so on) and transitional areas (areas undergoing change from one land use to another) make up 4.0 percent of the land use, and open water accounts for 2.5 percent.

Water-Quality Issues

Water-quality issues in the study area include contamination of the shallow aquifers from urban and industrial sources; runoff from impermeable surfaces; irrigation runoff; agricultural runoff and infiltration of fertilizers, pesticides, and dissolved salts; municipal wastewater discharge and individual sewage and disposal system contamination; and brine contamination associated with oil and gas wells. The U.S. Department of Agriculture (Schuff, 1992) has shown that ground water in aquifers in the vicinity of large feedlot operations in the study area typically has elevated concentrations of dissolved nitrate. One possible source of this nitrate is leaching of nitrogen from manure after its application to fields. Both point- and nonpoint-source pollution effects on water quality can be observed in urban areas. Point sources to ground water include landfills, gasoline-storage tanks, and contaminated industrial and commercial sites. Some of these sites are being investigated and remediated under the U.S. Environmental Protection Agency’s (USEPA) Comprehensive Environmental Response, Compensation, and Liability Act (CERCLA) and Resource Conservation and Recovery



Base from Denver Water Board, 1999 and
Colorado Department of Transportation, 1998.

Figure 4. Land-use classifications in the study area in 1990.

Act (RCRA) programs. There are 13 USEPA Superfund CERCLA sites in the study area, including Lowry Landfill, Marshall Landfill, Air Force Plant PJKS, Denver Radium Site, Rocky Flats, Sand Creek Industrial, and Rocky Mountain Arsenal.

METHODS OF DATA ANALYSIS

Methods of water-quality data analysis included retrieving historical water-quality data in electronic format, performing screening and quality assurance, and presenting summary statistics and statistics by decade and land use and comparing these to Federal drinking-water standards.

Data Sources and Screening. Ground-water-quality data collected by the USGS and by the Water Quality Division of the Colorado Department of Public Health and Environment (CDPHE) that were available in electronic format were used in this report. Most water-quality information was obtained from wells sampled by the USGS and stored in the National Water Information System (NWIS) database. There were 1,583 water-quality sampling events (for any number of analytes) for 807 sites in the NWIS database for the study area. The CDPHE provided data from 2,287 water-quality sampling events for 1,331 sites in the study area. All historical records were queried for these 2,138 sites. The earliest records in the database are from 1954.

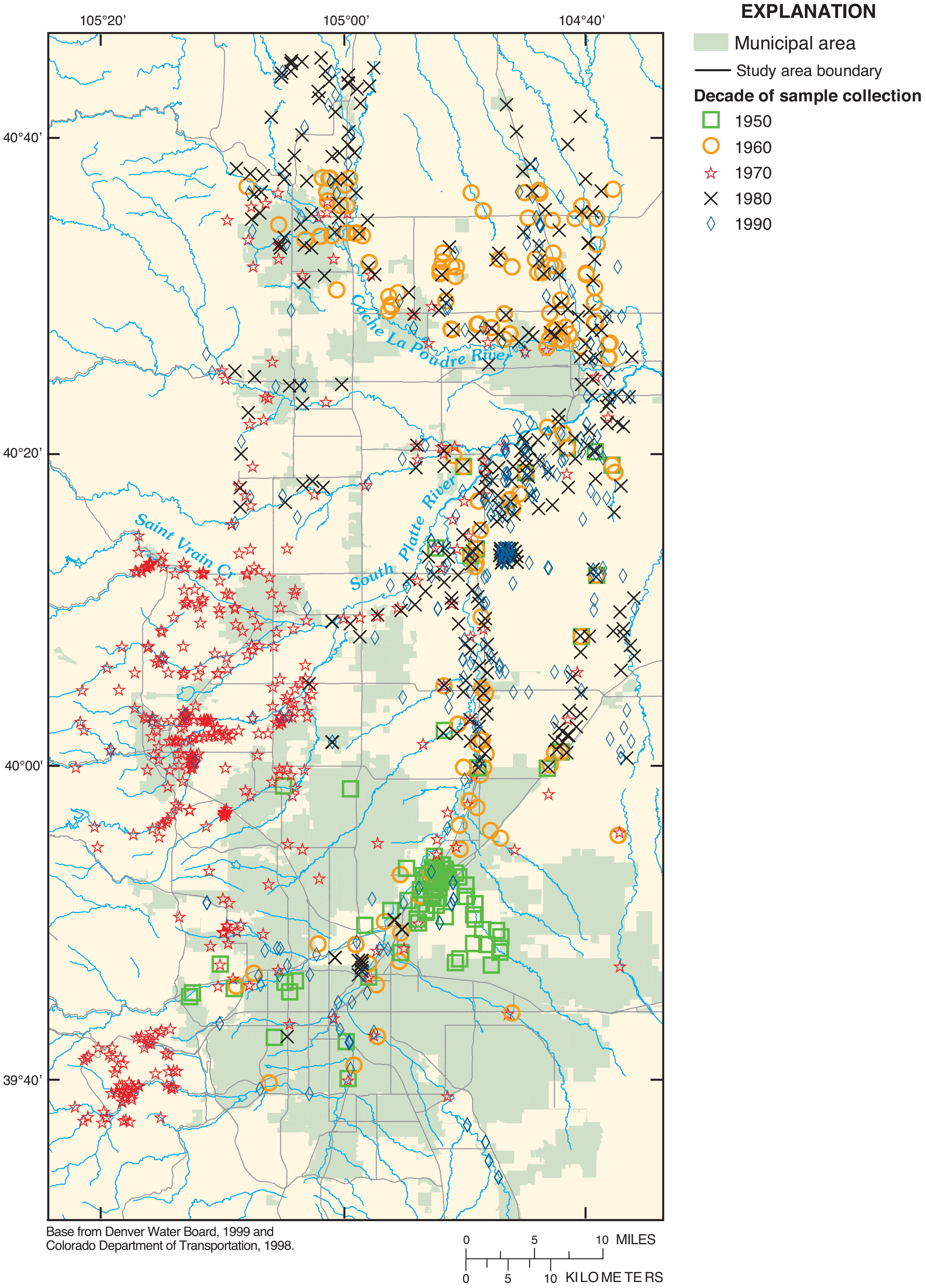
The most definitive results for water-quality assessment of an area are derived from a carefully designed study with systematic data collection. The data summarized in this report were collected by different agencies, at varying locations and times, and for multiple purposes. This situation creates copious variability in distribution over time and space. Figure 5 shows the spatial distribution of sampling by decade of sample collection and illustrates that the locations of sampling differed greatly from decade to decade. Many sites in the western part of the study area were sampled in the 1970's only, whereas in the eastern part of the study area, more data were collected in the 1980's and 1990's.

Wells are not uniformly distributed across the study area but are concentrated in areas where various ground-water studies have been or are being done. These might be studies of ground-water interaction with surface water near rivers and streams (for example, the South Platte National Water-Quality Assessment [NAWQA]), or near specific sites where ground water may be affected by human activity, such as Rocky Mountain Arsenal, or an area where sewage sludge was used for fertilizer (Johncox and Gaggiani, 1991). Wells in these areas were frequently sampled more than once, and some wells were sampled more than 10 times (fig. 6). The western part of the study area, an area with scattered well distribution, was sampled as part of general ground-water studies where samples were collected from existing domestic wells (Hall and others, 1979; Hall and Johnson, 1979).

Datasets from each source were screened separately before being combined. Results of chemical analyses from the CDHPE were not used if there was no information about the principal screened aquifer or well depth, if the well depth was greater than 150 feet below land surface, or if there was no depth information and the aquifer was Precambrian rock or Pierre Shale. The locations of CDPHE well sites that did not have latitude and longitude coordinates were projected on a map using Arc/INFO. Only data from wells meeting the aquifer and depth criteria of this study were obtained from the NWIS database, and all NWIS site data included latitude and longitude coordinates. Data from the two sources were combined for a total of 3,870 sampling events at 2,138 well sites. All the well sites for which data were evaluated are shown in figure 1.

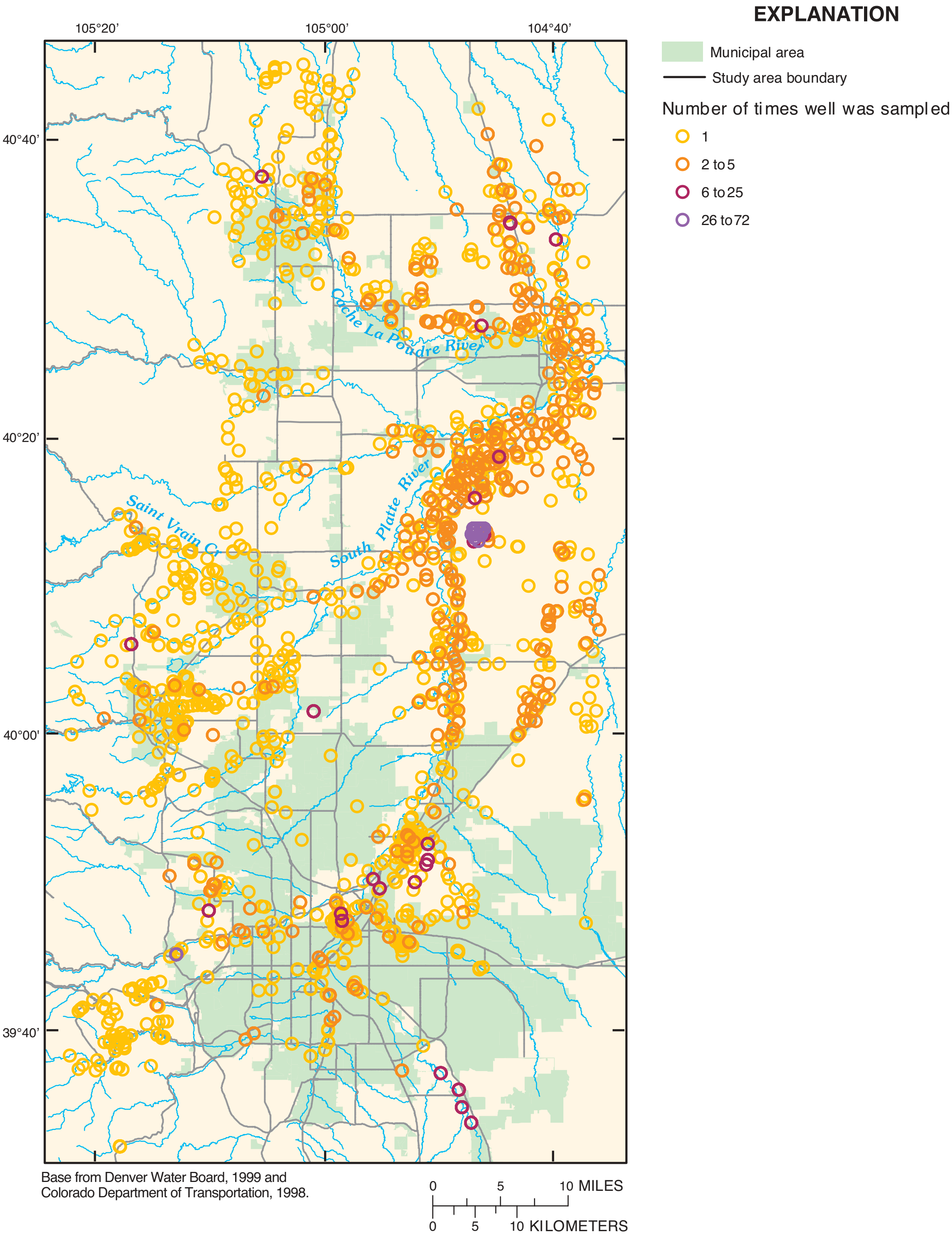
Well use is unknown for 1,191 of the 2,138 sampling sites (table 1). Most of the remaining wells are monitoring wells (659). Lithologic unit of the screened interval is unknown for 790 of the 2,138 sites (table 2). Most of the wells (1,115) are screened in alluvium. Wells that are not screened in the alluvium are still considered wells of the shallow aquifer because no wells deeper than 150 feet were used in this study. It is likely that these wells are located in areas of subcrops and outcrops of the deeper Denver Basin formations (fig. 2).

Data Quality Assurance. Quality assurance of data typically involves an examination of field methods, field quality-control samples, laboratory methods, and any other information associated with the analytical results. Quality assurance was a responsibility of each individual study for which data were collected. Data-quality information is not always included with the data in the database. For much of the data, information about analytical methods, sample-collection techniques, and quality assurance was not available. Because quality-assurance and analytical-



Base from Denver Water Board, 1999 and
Colorado Department of Transportation, 1998.

Figure 5. Temporal distribution of samples.



Base from Denver Water Board, 1999 and
Colorado Department of Transportation, 1998.

Figure 6. Number of sampling events at wells.

Table 1. Water use for wells in the study area

Water use	Number of wells
Domestic	70
Industrial	3
Irrigation	58
Livestock	17
Monitoring well	659
Private	131
Recreation	1
Spring	5
Water supply	3
Unknown	1,191
Total	2,138

Data Compilation and Comparison. Nonparametric summary statistics (Helsel and Hirsch, 1992) of the data were calculated using the most recent value from each site. Many constituents had data that were reported as less than the analytical detection limit. Because the data are from multiple studies and times, these detection limits usually vary for any constituent. Summary statistics for datasets that contain values less than the detection limit were estimated using robust lognormal probability plotting for mean and standard deviation, and the adjusted lognormal maximum likelihood method for the median and quartiles (Helsel and Cohn, 1988). For constituents where all data were above the detection limit, summary statistics were calculated using conventional methods.

Table 2. Lithology of well sites in the study area

Lithologic unit	Number of wells
Alluvium	1,115
Alluvium/Arapahoe	61
Alluvium/Laramie	3
Denver	1
Greenhorn LS	10
Laramie/Fox Hills	8
Fox Hills	22
Precambrian	125
Bedrock	3
Unknown	790
Total	2,138

Summary statistics include the mean, standard deviation, median, and interquartile range (IQR). The mean and standard deviation can be positively skewed by a few high values, implying greater occurrence and greater variability of a constituent than actually exists. Median and IQR are often better alternatives for estimating the central tendency and variability of a dataset (Helsel, 1990). The median is the value of which 50 percent of the data is above and 50 percent is below. The IQR is the 75th percentile minus the 25th percentile. Both the median and IQR are relatively unaffected by the lowest and highest data values.

The most recent values from each site for selected constituents were mapped for analysis of spatial distribution. Summary statistics were calculated for selected constituents by decade and 1990 land use. A Piper diagram was used to identify water types from major ion samples. Properties and constituents were compared to drinking-water standards (U.S. Environmental Protection Agency, 2002) because of the possibility of future use of shallow ground water as a drinking-water supply.

SUMMARY OF WATER-QUALITY CHARACTERISTICS

Summary statistics were calculated for those constituents or properties where no data were reported below the detection limit. As noted previously, summary statistics for data that were reported at less than the detection limit were estimated using robust lognormal probability plotting for mean and standard deviation, and the adjusted lognormal maximum likelihood method for the median and quartiles. These methods are not accurate if 80 percent or more of the data are less than the detection limit.

Physical Properties and Inorganic Compounds

Statistical Summaries and Spatial Distribution. More than 80 percent of the data were below detection limit for beryllium, cadmium, lead, mercury, and silver; therefore, summary statistics could not be estimated for those constituents. The calculated and estimated statistics are shown in table 3.

Spatial distribution for specific conductance, sulfate, and chloride are shown in figures 7–9, respectively. Ground water in the study area included fresh to saline water, based on specific-conductance data (table 3). The mean and median values for specific conductance were 1,760 microsiemens per centimeter (µS/cm) and 1,340 µS/cm. Specific conductance values between 1,000 and 5,000 µS/cm were widespread across the study area (fig. 7). Areas of elevated sulfate (fig. 8) were not coincident with areas of elevated chloride (fig. 9) except in areas of known organic contamination from waste sites. Sources of sulfate can be geologic or anthropogenic. Anthropogenic sources can include fertilizer application, augmentation of soils with gypsum, road treatment, and organic contamination. Geologic sources include shales (Hem, 1992). Pierre Shale and Laramie Formation shales outcrop in the northern part of the study area (fig. 2), which may account for elevated sulfate in the north and northeast parts of the study area. Chloride concentrations are generally less than 100 milligrams per liter (mg/L) across the study area; the median is 44.0 mg/L and the 75th quartile is 110 mg/L. Chloride is at greater concentrations in isolated areas of known contamination from waste sites (fig. 9).

Nitrogen concentrations in ground water can come from municipal or residential wastewater discharge, animal wastes, fertilizer application, or confined animal feeding operations (Wilde and others, 2000; Mueller and Helsel, 1992). Nitrate is anionic and stable in aerobic environments and, therefore, is more common in shallow ground water than ammonia or nitrite. Ammonia is biologically attenuated and is also converted to nitrate through nitrification. Nitrite also tends to be converted to nitrate in ground water under oxidizing conditions.

Nitrite is not common in natural ground-water conditions (Hem, 1992), and nitrate plus nitrite is usually composed of all or mostly nitrate. Most samples in this database were analyzed for nitrate plus nitrite rather than for just nitrate; therefore, nitrate and nitrate plus nitrite concentrations were combined for the purpose of this study and will be hereinafter referred to as “nitrate concentrations.” The mean and median concentrations for nitrate were 9.96 mg/L and 5.50 mg/L, respectively. Most of the nitrate samples greater than 10 mg/L were collected near rivers and streams, usually downgradient from the Denver metropolitan area and the Boulder-Longmont area (fig. 10). There were many wells with nitrate concentrations greater than 10 mg/L in the area downstream from the confluence of the South Platte River with the St. Vrain Creek. There were areas of elevated nitrate concentrations that were not along the South Platte River, however. In the southwest corner of the study area, along Interstate Highway 70, there were several wells with nitrate concentrations greater than 10 mg/L in a residential area. These concentrations were possibly from individual sewage disposal system use or from fertilizer application to land (Hall and others, 1981).

Distribution Over Time and by Land Use. Summary statistics were calculated or estimated by decade for specific conductance, sulfate, chloride, and nitrate (table 4). The summary statistics by decade are influenced by the temporal variability of data across the study area (fig. 5). The greatest median for specific conductance was in the 1980’s, but only 60 samples were collected in that decade, so the greater value is not necessarily representative of the entire study area. The greatest median concentration for sulfate was from the 1960’s, but many samples were collected from the north and northeast parts of the study area in that decade (fig. 5), in areas where sulfate concentrations are greater, possibly because of geology (fig. 8). The greatest median concentration for chloride was in the 1950’s, but that is probably because most of the samples collected at that time were from the Rocky Mountain Arsenal, a site contaminated with chlorinated organic compounds (U.S. Geological Survey, 1997). Median chloride concentrations have increased from the 1970’s to the 1990’s from 14.0 mg/L to 87.0 mg/L, and the IQR has also increased, indicating greater variability in chloride concentrations. The median and IQR for nitrate were greatest in the 1990’s at 11 mg/L and 13.8 mg/L. The median values of specific conductance, chloride, and nitrate from the 1970’s are different and less than values from the 1980’s and 1990’s, which indicates that water quality of the western part of the study area generally is different than the rest of the study area.

Summary statistics were calculated or estimated by land-use category for specific conductance, sulfate, chloride, and nitrate (table 5). The median values of specific conductance for all land uses are similar, with the median for forested areas being the lowest at 580 µS/cm. The greatest median concentration for chloride is in transportation/transitional areas at 85.0 mg/L. Chloride may be introduced to ground water in these areas from runoff of road deicers or chlorinated organic compounds. The median for nitrate is greatest where the land is cultivated (11.3 mg/L) or used for agricultural business (8.80 mg/L). These median nitrate concentrations are

Table 3. Summary of statistical analysis of data for selected properties and constituents obtained from 2,138 wells in the study area, 1954–98

[All data for dissolved constituents unless otherwise indicated; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; %, percent; $CaCO_3$, calcium carbonate; -- , not applicable]

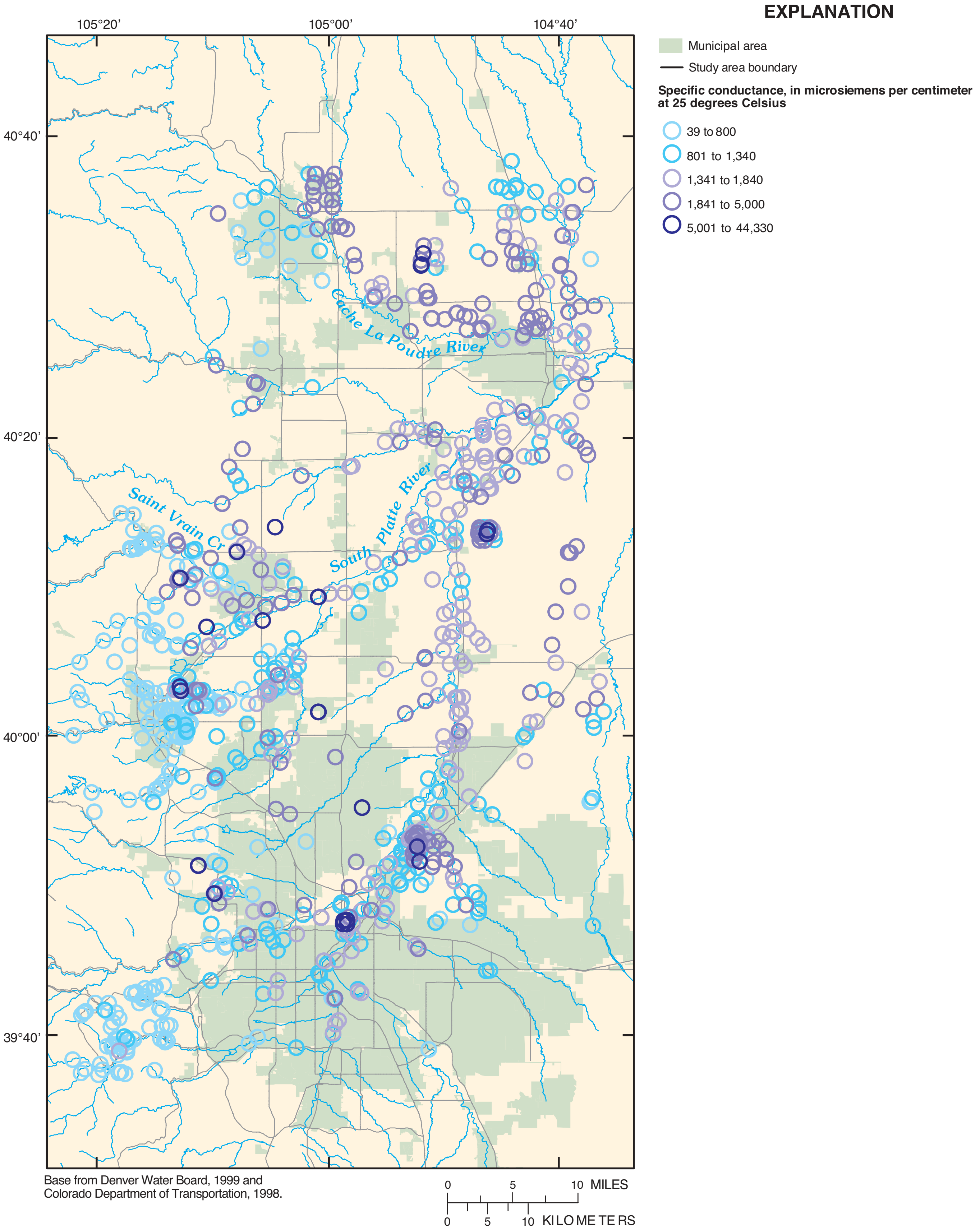
Constituent or property	Units	Observations	Number of observations less than detection limit	Percent less than detection limit	Number of detection limits	Maximum detection limit	Mean	Standard deviation	Median	Interquartile range	25th quartile	75th quartile
Physical properties												
Specific conductance, lab	µS/cm	974	0	--	--	--	1,760	2,550	1,340	1,040	800	1,840
pH, field	pH units	605	0	--	--	--	7.28	0.55	7.30	0.50	7.10	7.60
Major ions												
Calcium	mg/L	1,051	0	--	--	--	185	208	140	118	100	218
Magnesium	mg/L	814	0	--	--	--	70.6	80.6	47.0	52.0	29.0	81.0
Sodium	mg/L	1,170	0	--	--	--	201	589	130	81.7	95.0	177
Potassium	mg/L	1,070	19	1.8	5	2.67	22.2	280	4.20	5.40	1.00	6.40
Bicarbonate alkalinity, as $CaCO_3$	mg/L	740	0	--	--	--	361	163	350	110	300	410
Carbonate alkalinity, as $CaCO_3$	mg/L	5	0	--	--	--	70.0	75.5	18.0	121	18.0	139
Alkalinity, as $CaCO_3$	mg/L	549	0	--	--	--	323	240	300	112	250	362
Sulfate	mg/L	1,030	12	1.2	2	10.0	568	811	320	442	197	639
Chloride	mg/L	1,293	0	--	--	--	139	536	44.0	93.0	17.0	110
Fluoride	mg/L	493	0	--	--	--	1.80	13.9	1.00	0.600	0.700	1.30
Silica	µg/L	472	0	--	--	--	18.7	7.18	18.0	8.00	14.0	22.0
Dissolved solids	mg/L	1,014	0	--	--	--	1,380	1,690	1,020	664	774	1,440
Total suspended solids	mg/L	3	0	--	--	--	224	317	49.0	278	41.5	320
Nutrients												
Nitrate, as N	mg/L	576	24	4.2	5	1.00	13.7	50.4	9.00	11.8	4.22	16.0
Nitrite, as N	mg/L	164	95	57.9	4	0.760	0.020	0.042	1.00	0.00	1.00	1.00
Nitrate plus nitrite, as N	mg/L	605	32	5.3	5	0.500	6.93	10.7	2.90	7.30	1.00	8.30
(Nitrate plus nitrite) + Nitrate as N[1]	mg/L	1,078	55	5.1	7	1.00	9.96	37.4	5.50	11.8	1.20	13.0
Nitrogen, ammonia, as N	mg/L	155	37	23.9	5	0.200	0.584	2.66	1.00	0.00	1.00	1.00
Phosphorus	mg/L	259	39	15.1	5	6.00	0.178	0.483	1.00	0.00	1.00	1.00
Phosphate	mg/L	19	12	63.2	2	0.040	0.038	0.083	1.00	0.00	1.00	1.00
Orthophosphate	mg/L	241	0	--	--	--	0.392	1.03	0.120	0.250	0.060	0.310
Trace elements												
Aluminum	µg/L	331	135	40.8	20	250	2,490	15,600	1.00	0.00	1.00	1.00
Arsenic	µg/L	420	301	71.7	17	315	43.7	533	1.00	0.00	1.00	1.00
Barium	µg/L	379	38	10	9	200	186	806	1.00	0.00	1.00	1.00
Beryllium	µg/L	253	223	88.1	15	30.0	--	--	--	--	--	--

Table 3. Summary of statistical analysis of data for selected properties and constituents obtained from 2,138 wells in the study area, 1954–98—Continued

[All data for dissolved constituents unless otherwise indicated; mg/L, milligrams per liter; µg/L, micrograms per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; %, percent; $CaCO_3$, calcium carbonate; -- , not applicable]

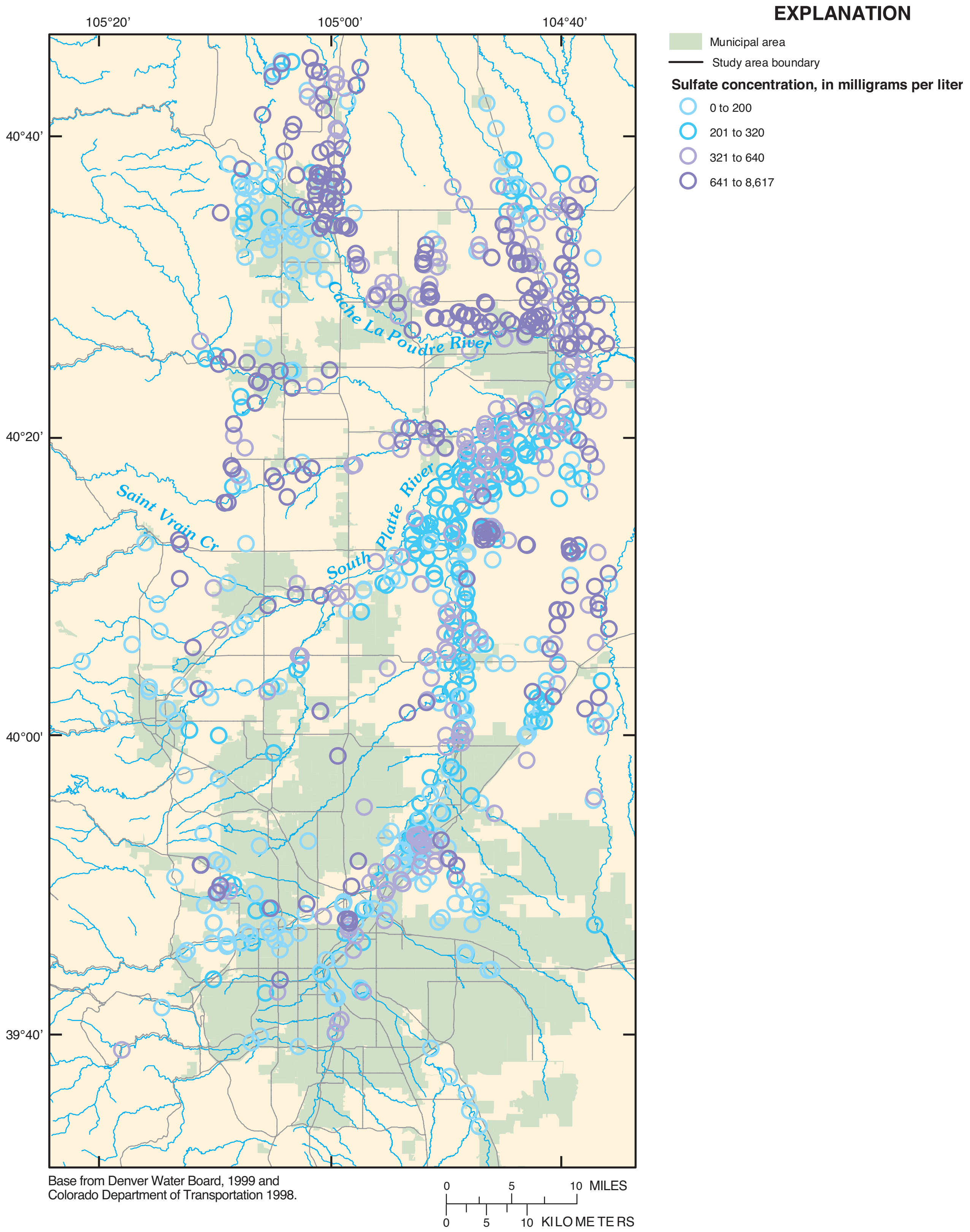
Constituent or property	Units	Observations	Number of observations less than detection limit	Percent less than detection limit	Number of detection limits	Maximum detection limit	Mean	Standard deviation	Median	Interquartile range	25th quartile	75th quartile
Boron	µg/L	416	12	2.9	3	140	289	631	240	179	148	328
Cadmium	µg/L	457	369	80.7	15	36.0	--	--	--	--	--	--
Chromium	µg/L	414	243	58.7	21	500	9.70	20.1	1.00	0.00	1.00	1.00
Copper	µg/L	422	237	56.2	23	50.0	26.0	160	1.00	0.00	1.00	1.00
Iron	µg/L	689	115	16.7	18	1,000	4,610	26,700	1.00	0.00	1.00	1.00
Lead	µg/L	457	370	81	16	885	--	--	--	--	--	--
Lithium	µg/L	34	0	--	--	--	52.6	53.2	28.5	36.8	21.2	58.0
Manganese	µg/L	581	158	27.2	12	20.0	1,920	15,600	20.0	324	1.00	325
Mercury	µg/L	225	203	90.2	9	100	--	--	--	--	--	--
Selenium	µg/L	406	153	37.7	13	71.0	60.2	435	1.00	0.00	1.00	1.00
Silver	µg/L	266	236	88.7	20	60.0	--	--	--	--	--	--
Zinc	µg/L	430	95	22.1	15	50.0	6,480	75,300	1.00	52.2	1.00	53.2
Organic carbon												
Total organic carbon	mg/L	44	1	--	--	--	6.75	7.41	4.35	3.62	3.48	7.10
Dissolved organic carbon	mg/L	77	0	--	--	--	4.14	4.28	3.10	1.90	2.10	4.00
Suspended organic carbon	mg/L	4	2	--	--	--	0.200	0.082	0.200	0.050	0.175	0.225

[1] Nitrite is not common in natural ground-water conditions, and nitrate plus nitrite is usually composed of all or mostly nitrate. Most samples in this database were analyzed for nitrate plus nitrite rather than for just nitrate; therefore, nitrate and nitrate plus nitrite concentrations were combined for the purpose of this study and are referred to in the text as “nitrate concentrations.”



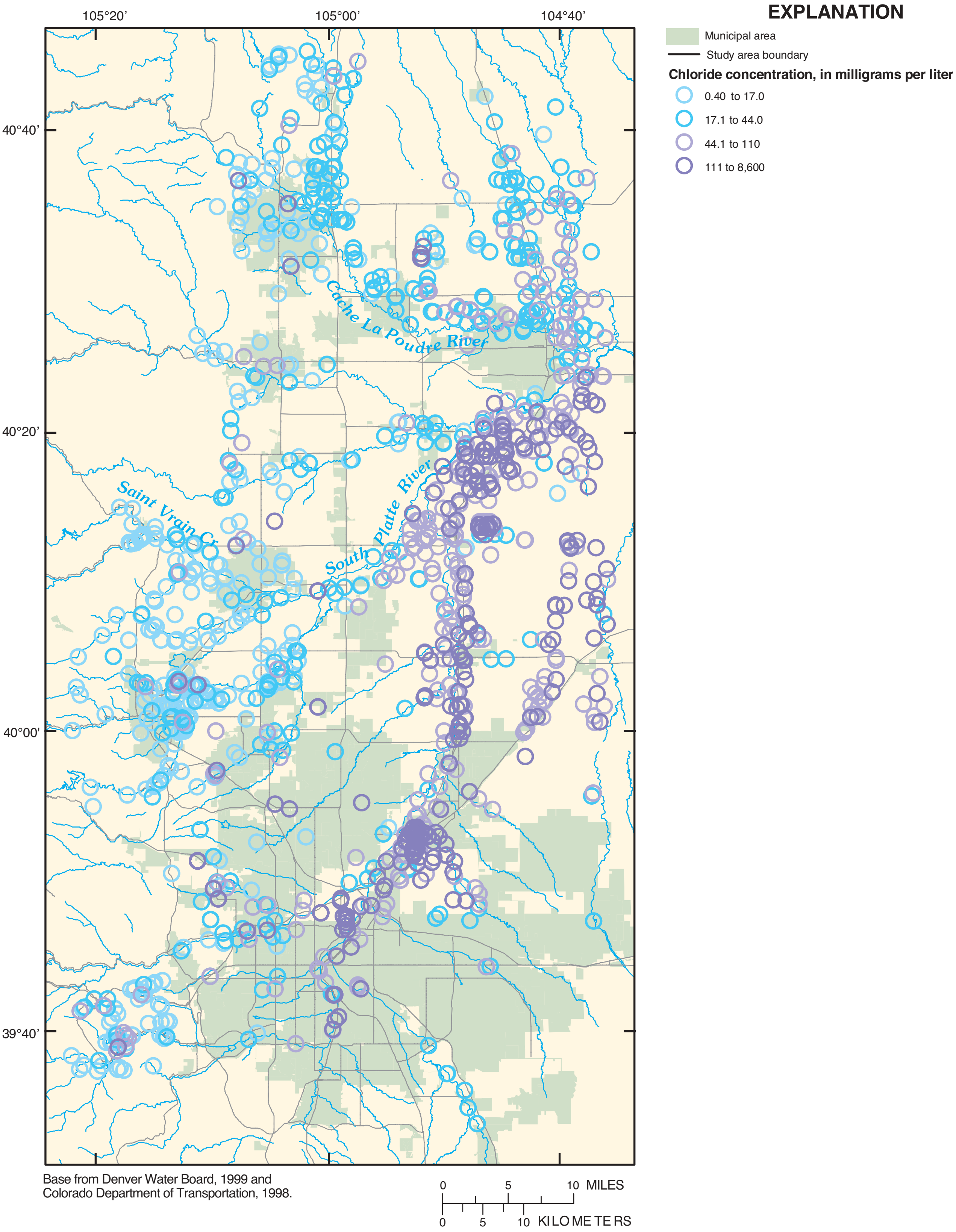
Base from Denver Water Board, 1999 and
Colorado Department of Transportation, 1998.

Figure 7. Spatial distribution of specific-conductance values.



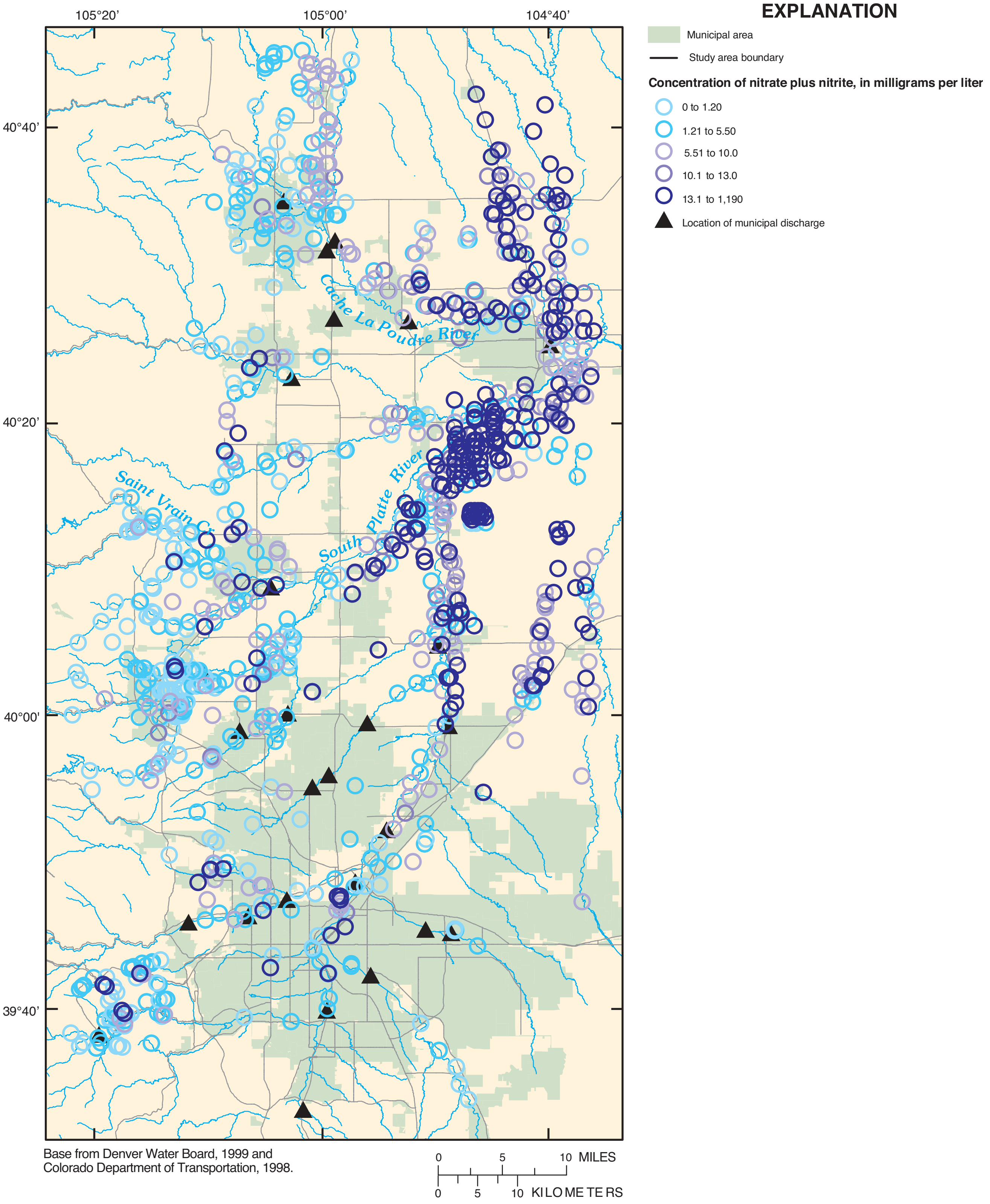
Base from Denver Water Board, 1999 and
Colorado Department of Transportation 1998.

Figure 8. Spatial distribution of sulfate concentrations.



Base from Denver Water Board, 1999 and
Colorado Department of Transportation, 1998.

Figure 9. Spatial distribution of chloride concentrations.



Base from Denver Water Board, 1999 and
Colorado Department of Transportation, 1998.

Figure 10. Spatial distribution of nitrate plus nitrite concentrations.

Table 4. Summary statistics for specific conductance, sulfate, chloride, and nitrate by decade

[N, number of observations; NLT, number of observations less than detection limit; %LT, percentage of observations that are less than the detection limit; IQR, interquartile range; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; -- , not applicable]

Decade	Specific conductance (µS/cm)				Sulfate (mg/L)				Chloride (mg/L)				Nitrate[1] (mg/L)				
	N	**NLT**	**Median**	**IQR**	**N**	**NLT**	**Median**	**IQR**	**N**	**NLT**	**Median**	**IQR**	**N**	**NLT**	**% LT**	**Median**	**IQR**
1950	90	0	1,385	1,023	87	0	220	215	87	0	110	154	0	0	--	--	--
1960	154	0	1,710	1,120	153	0	520	810	154	0	35.0	75.0	44	0	0	6.00	4.00
1970	430	0	828	1,062	149	0	310	470	414	0	14.0	23.9	410	4	1	2.00	5.20
1980	60	0	2,654	4,627	308	0	381	533	309	0	66.0	87.0	150	15	10	5.80	9.51
1990	240	0	1,460	588	333	0	290	260	329	0	87.0	96.0	474	36	7.6	11.0	13.8

[1] Nitrite is not common in natural ground-water conditions, and nitrate plus nitrite is usually composed of all or mostly nitrate. Most samples in this database were analyzed for nitrate plus nitrite rather than for just nitrate; therefore, nitrate and nitrate plus nitrite concentrations were combined for the purpose of this study and are referred to in the text as “nitrate concentrations.”

Table 5. Summary statistics for specific conductance, sulfate, chloride, and nitrate by land-use category

[N, number of observations; NLT, number of observations less than detection limit; %LT, percentage of observations that are less than the detection limit; IQR, interquartile range; mg/L, milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius]

Land-use category	Specific conductance (µS/cm)				Sulfate (mg/L)				Chloride (mg/L)				Nitrate (mg/L)				
	N	**NLT**	**Median**	**IQR**	**N**	**NLT**	**Median**	**IQR**	**N**	**NLT**	**Median**	**IQR**	**N**	**NLT**	**% LT**	**Median**	**IQR**
Agricultural business	27	0	1,560	1,010	37	0	300	447	38	0	57.6	65.3	35	1	2.9	8.80	13.0
Commercial/ Industry/ Mixed urban	126	0	1,460	1,260	120	0	300	529	134	0	59.4	118	100	7	7.0	3.80	9.75
Cultivated	279	0	1,620	887	416	0	369	485	441	0	68.0	91.0	381	16	4.2	11.3	13.1
Forest/Orchard/ Shrubland	35	0	580	960	18	0	265	141	38	0	18.0	76.0	37	0	0.0	0.65	7.87
Natural herbaceous	143	0	1,120	1,160	133	0	300	310	175	0	66.0	148	108	4	3.7	2.70	7.82
Residential	293	0	932	1,010	172	0	290	347	330	0	18.5	45.3	292	6	2.1	2.80	6.92
Transportation/ transitional	57	0	1,410	870	52	0	125	371	54	0	85.0	134	45	16	35.6	1.20	3.80
Water	7	0	1,520	511	9	0	250	199	9	0	75.0	111	4	0	0.0	6.00	3.28
Unknown	7	0	1,080	865	73	0	477	678	74	0	32.0	43.8	76	5	6.6	5.85	8.70

several times greater than the medians for other land-use categories, which may reflect use of nitrogen fertilizers and the presence of animal feeding operations.

Ion Analysis by Trilinear Diagram. A Piper trilinear diagram (fig. 11) is a plot of concentrations of major ions in water that visually depicts the proportions of different ions in a group of water samples. Only major ion data with an ion balance within

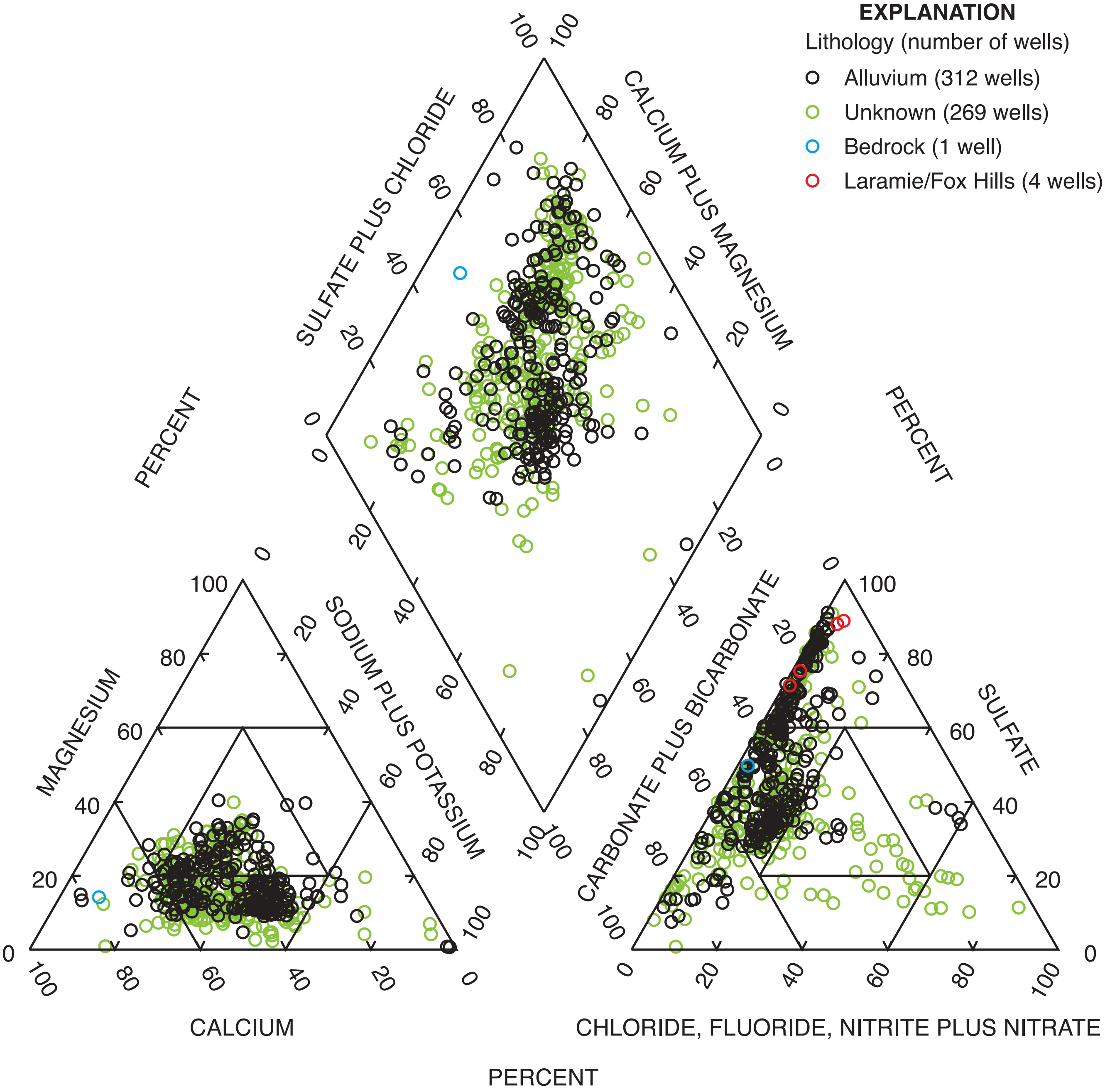


Figure 11. Ion data balanced within 5 percent.

5 percent were used to construct the Piper diagram. Of the 586 major ion samples that balanced within 5 percent, 312 are from alluvial wells, 269 from wells of unknown lithology, 1 from a bedrock well, and 4 from wells in the Laramie-Fox Hills aquifer. The majority of the samples do not show much variability between lithology on the diagram. There are some samples for which the lithology is unknown that have a smaller proportion of sulfate than most of the other samples. The majority of the 586 water samples have a slightly higher proportion of calcium plus magnesium than of sodium plus potassium. Calcium and sodium plus potassium are proportionally greater than magnesium. The Piper diagram shows that, for 390 of the 586 major ion samples that balanced within 5 percent, sulfate is proportionally substantially greater than bicarbonate.

Organic Compounds

Statistical Summaries and Spatial Distribution. Table 6 lists selected organic constituents for which 80 percent or more of the data were less than the detection limit.

Estimated summary statistics for organic constituents for which more than 20 percent of the data were reported greater than the detection limit are shown in table 7. Spatial distribution for those compounds for which more than 40 percent of the data were above the detection limit (atrazine, methyl-*tert*-butylether, and prometon) are shown in figures 12–14. The distribution of these organics is not widespread across the study area; not many sites, however, were sampled for these constituents.

SUMMARY OF WATER-QUALITY CHARACTERISTICS COMPARED TO DRINKING-WATER STANDARDS

Although only a small proportion of the sampling sites are drinking water wells, it is possible that the shallow ground water of the study area may be used as a drinking-water supply in the future. For this reason, and as a general measure of quality against a standard, properties and constituents were compared to U.S. Environmental Protection Agency primary and secondary drinking-water standards (U.S. Environmental Protection Agency, 2002). Table 8 presents the number of exceedances, the percentage of the total data exceeded, and the percentage of the detections exceeded for each constituent.

Inorganic Compounds

Chloride concentrations exceeded the secondary standard of 250 mg/L in 7.5 percent of samples. Sulfate concentrations exceeded the secondary drinking-water standard of 250 mg/L in 63.4 percent of samples. Nitrate concentrations exceeded the primary drinking-water standard of 10 mg/L in 31.9 percent of samples.

Trace elements that exceeded the drinking-water standard in more than 10 percent of the samples are aluminum, cadmium, iron, and manganese. Aluminum exceeded the secondary drinking-water standard of 0.050 mg/L in 38.4 percent of the samples. Cadmium exceeded the primary drinking-water standard of 0.005 mg/L in 11.6 percent of the samples. Iron exceeded the secondary drinking-water standard of 0.3 mg/L in 21.8 percent of the samples. Manganese exceeded the secondary drinking-water standard of 0.05 mg/L in 38.9 percent of the samples.

Organic Compounds

Organic compounds that exceeded the drinking-water standard in more than 10 percent of the samples were the following: 1,1-dichloroethylene exceeded the primary drinking-water standard of 0.007 mg/L in 10.1 percent of samples; tetrachloroethylene exceeded the primary drinking-water standard of 0.005 mg/L in 13.1 percent of samples; and trichloroethylene exceeded the primary drinking-water standard of 0.005 mg/L in 15.7 percent of samples. Compounds that exceeded the drinking-water standard in more than 5 percent of samples were the following: benzene exceeded the primary drinking-water standard of 0.005 mg/L in 8.6 percent of samples, and dichloromethane exceeded the primary drinking-water standard of 0.005 mg/L in 6.7 percent of samples.

SUMMARY

The Front Range Infrastructure Resources Project was a multidisciplinary effort by the USGS to

Table 6. Number of observations and number of observations less than the detection limit for organic constituents that were detected in less than 80 percent of samples

Constituent	Observations	Number of observations less than detection limit	Percent less than detection limit
1,1,1-Trichloroethane	568	454	79.9
1,1,2-Trichloroethane	330	316	95.8
1,1-Dichloroethane	502	432	86.1
1,1-Dichloroethylene	487	419	86
1,2,4-Trichlorobenzene	183	178	97.3
1,2,4-Trimethylbenzene	48	47	97.9
1,2-Dichlorobenzene	139	134	96.4
1,2-Dichloroethane	561	530	94.5
1,2-Dichloropropane	302	299	99
1,3,5-Trimethylbenzene	48	47	97.9
1,4-Dichlorobenzene	264	251	95.1
2,4,5-TP (Silvex)	55	55	100
2,4-D	89	88	98.9
2,4-D,B	50	50	100
2,6-Diethylaniline	50	50	100
Acetochlor	5	5	100
Alachlor	125	124	99.2
Aldicarb	109	109	100
Aldicarb sulfoxide	55	54	98.2
alpha-HCH, alpha-BHC, alpha-Lindane	69	69	100
Atrazine	125	56	44.8
Azinphos-methyl	71	71	100
Benfluralin	120	120	100
Bentazon	50	50	100
Benzene	593	514	86.7
Benzo(a)pyrene (PAHs)	84	83	98.8
Biphenyls (PCBs)	4	4	100
Bromacil	55	54	98.2
Bromoxynil	50	50	100
Butylate	79	79	100
Carbaryl	55	55	100
Carbofuran	109	108	99.1
Carbon tetrachloride	543	505	93
Chlordane, gamma	15	15	100
Chlordane, alpha	21	21	100
Chlorobenzene	443	428	96.6
Chlorodibromomethane	503	500	99.4
Chloroethane (ethyl chloride)	377	368	97.6
Chloroethene (vinyl chloride)	437	418	95.7
Chloroform	577	491	85.1

Table 6. Number of observations and number of observations less than the detection limit for organic constituents that were detected in less than 80 percent of samples —Continued

Constituent	Observations	Number of observations less than detection limit	Percent less than detection limit
Chloromethane (methyl chloride)	179	178	99.4
Chlorpyrifos	125	125	100
cis-1,2-Dichloroethylene	480	416	86.7
Clopyralid	50	50	100
Cyanazine	125	115	92
Cycloate	8	8	100
Dacthal, mono-acid	50	49	98
DCPA	93	92	98.9
Deethylatrazine	26	20	76.9
Deisopropylatrazine	8	5	62.5
Diazinon	100	95	95
Dicamba	55	55	100
Dichlorobromomethane	507	503	99.2
Dichlorodifluoromethane (CFC 12)	94	92	97.9
Dichloroethylene	94	93	98.9
Dichloromethane (methylene chloride)	614	531	86.5
Dichloropropane	94	93	98.9
Dichlorprop (2,4-DP)	50	50	100
Dieldrin	94	87	92.6
Dimethoate	4	4	100
Dinoseb	50	50	100
Disulfoton	79	79	100
Diuron	49	48	98
Endrin	70	67	95.7
EPTC	95	94	98.9
Ethalfluralin	50	50	100
Ethoprop	50	50	100
Ethylbenzene (phenylethane)	469	420	89.6
Fonofos	8	8	100
Heptachlor	70	67	95.7
Heptachlor epoxide	70	67	95.7
Hexachlorobenzene	74	74	100
Hexachlorocyclopentadiene	74	74	100
Isopropyl benzene	48	44	91.7
Lindane	112	112	100
Linuron	50	50	100
Malathion	55	55	100
MCPA	50	50	100
Methoxychlor	72	72	100
Methyl parathion	95	95	100
Methyl-*tert*-butylether	81	44	54.3

Table 6. Number of observations and number of observations less than the detection limit for organic constituents that were detected in less than 80 percent of samples —Continued

Constituent	Observations	Number of observations less than detection limit	Percent less than detection limit
Metolachlor	116	85	73.3
Metribuzin	116	116	100
Molinate	50	50	100
Naphthaline	198	171	86.4
Napropamide	50	50	100
n-Butylbenzene	48	46	95.8
n-Propylbenzene	48	46	95.8
o-Dichlorobenzene	94	92	97.9
Oryzalin	50	50	100
Oxamyl (Vydate)	60	60	100
p,p-DDE	53	53	100
Parathion	55	55	100
Pebulate	50	50	100
Pendimethalin	50	50	100
Pentachlorophenol	2	1	50
Phorate	55	55	100
Picloram	55	55	100
p-Isopropyltoluene	48	48	100
Prometon	84	38	45.2
Pronamide	50	50	100
Propachlor	55	55	100
Propanil	50	50	100
Propargite	50	50	100
Propazine	8	8	100
Propham	55	55	100
Propoxur	55	55	100
sec-Butylbenzene	48	45	93.8
Simazine	94	68	72.3
Styrene	330	330	100
Tebuthiuron	45	34	75.6
Terbacil	77	77	100
Terbufos	74	74	100
tert-Butylbenzene	48	46	95.8
Tetrachloroethylene	664	494	74.4
Toluene	495	410	82.8
Toxaphene	21	21	100
trans-1,2-Dichloroethylene	377	339	89.9
Triallate	50	50	100
Trichloroethylene	669	505	75.5
Triclopyr	50	50	100
Trifluralin	125	125	100
Xylenes (total)	566	498	88

Table 7. Summary of statistical analysis of data for selected organic constituents obtained from 2,138 wells in the study area, 1954–98

[All data for dissolved constituents; μg/L, micrograms per liter]

Constituent (μg/L)	Observations	Number of observations less than detection limit	Percent less than detection limit	Number of detection limits	Maximum detection limit	Mean	Standard deviation	Median	Interquartile range	25th quartile	75th quartile
Deethylatrazine	26	20	76.9	3	0.200	0.272	1.17	0.000	0.003	0.000	0.003
Deisopropylatrazine	8	5	62.5	1	0.200	0.331	0.724	0.024	0.272	0.003	0.275
Atrazine	125	56	44.8	7	2.00	0.205	0.377	0.035	0.190	0.006	0.196
Prometon	84	38	45.2	2	0.100	0.131	0.222	0.054	0.103	0.023	0.126
Simazine	94	68	72.3	4	0.200	0.007	0.009	0.005	0.006	0.003	0.009
Tebuthiuron	45	34	75.6	2	0.015	0.019	0.064	0.002	0.010	0.001	0.010
Tetrachloroethylene	664	494	74.4	16	1,000	66.5	434	1.00	0.000	1.00	1.00
Trichloroethylene	669	505	75.5	14	1,000	331	2,320	0.025	1.10	0.001	1.10
Methyl-*tert*-butylether	81	44	54.3	1	0.200	173	739	0.120	5.30	0.003	5.30
Metolachlor	116	85	73.3	5	0.400	0.028	0.082	0.002	0.010	0.000	0.010

Table 8. Comparison of concentrations of selected constituents in ground water to drinking-water standards

[mg/L, milligrams per liter; MCL, maximum contaminant level (primary drinking-water standard, USEPA, 2002); SS, secondary standard; MCL/TT, standard is the action level at which a treatment technique must be implemented by a water supplier if 10 percent of tap-water samples exceed the standard; %, percentage; USEPA, U.S. Environmental Protection Agency; -- , not applicable]

Constituent	USEPA drinking water standard			Number of observations	Number less than detection limit	Percentage less than detection limit	Exceedances		
	Standard	Units	Type				Number of exceedances	Percentage of total	Percentage of detections
Major ions									
Chloride	250	mg/L	SS	1,293	0	--	97	7.5	7.5
Fluoride	2.0	mg/L	SS	493	0	--	39	7.9	7.9
Fluoride	4.0	mg/L	MCL	493	0	--	10	2.0	2.0
Sulfate	250	mg/L	SS	1,030	12	1.2	653	63.4	64.1
Dissolved solids	500	mg/L	SS	1,014	0	--	932	91.9	91.9
Nutrients									
Nitrate[1]	10	mg/L	MCL	1,078	55	5.1	344	31.9	33.6
Nitrite	1	mg/L	MCL	164	95	57.9	0	0.0	0.0

Table 8. Comparison of concentrations of selected constituents in ground water to drinking-water standards—Continued

[mg/L, milligrams per liter; MCL, maximum contaminant level (primary drinking-water standard, USEPA, 2002); SS, secondary standard; MCL/TT, standard is the action level at which a treatment technique must be implemented by a water supplier if 10 percent of tap-water samples exceed the standard; %, percentage; USEPA, U.S. Environmental Protection Agency; -- , not applicable]

Constituent	USEPA drinking water standard			Number of observations	Number less than detection limit	Percentage less than detection limit	Exceedances		
	Standard	Units	Type				Number of exceedances	Percentage of total	Percentage of detections
Trace elements									
Aluminum	0.05 to 0.2	mg/L	SS	331	135	40.8	127/64	38.4/19.3	64.8/32.7
Arsenic	0.05	mg/L	MCL	420	301	71.7	10	2.4	8.4
Barium	2	mg/L	MCL	379	38	10	6	1.6	1.8
Beryllium	0.004	mg/L	MCL	253	223	88.1	2	0.8	6.7
Cadmium	0.005	mg/L	MCL	457	369	80.7	53	11.6	60.2
Chromium	0.1	mg/L	MCL	414	243	58.7	4	1.0	2.3
Copper	1.3	mg/L	MCL/TT	422	237	56.2	2	0.5	1.1
Iron	0.3	mg/L	SS	689	115	16.7	150	21.8	26.1
Lead	0.015	mg/L	MCL/TT	457	370	81	34	7.4	39.1
Manganese	0.05	mg/L	SS	581	158	27.2	226	38.9	53.4
Mercury	0.002	mg/L	MCL	225	203	90.2	3	1.3	13.6
Selenium	0.05	mg/L	MCL	406	153	37.7	35	8.6	13.8
Silver	0.10	mg/L	SS	266	236	88.7	0	0.0	0.0
Zinc	5	mg/L	SS	430	95	22.1	10	2.3	3.0
Organic compounds									
Atrazine	0.003	mg/L	MCL	125	56	44.8	0	0.0	0.0
Benzene	0.005	mg/L	MCL	593	514	86.7	51	8.6	64.6
1,1-Dichloroethylene	0.007	mg/L	MCL	487	419	86.0	49	10.1	72.1
cis-1,2-Dichloroethylene	0.07	mg/L	MCL	480	416	86.7	16	3.3	25.0
trans-1,2-Dichloroethylene	0.1	mg/L	MCL	377	339	89.9	4	1.1	10.5
Dichloromethane	0.005	mg/L	MCL	614	531	86.5	41	6.7	49.4
Ethylbenzene	0.7	mg/L	MCL	469	420	89.6	3	0.6	6.1
Simazine	0.004	mg/L	MCL	94	68	72.3	0	0.0	0.0
Tetrachloroethylene	0.005	mg/L	MCL	664	494	74.4	87	13.1	51.2
Toluene	1	mg/L	MCL	495	410	82.8	15	3.0	17.6
1,1,1-Trichloroethane	0.2	mg/L	MCL	568	454	79.9	26	4.6	22.8
Trichloroethylene	0.005	mg/L	MCL	669	505	75.5	105	15.7	64.0
Xylenes (total)	10	mg/L	MCL	566	498	88.0	2	0.4	2.9

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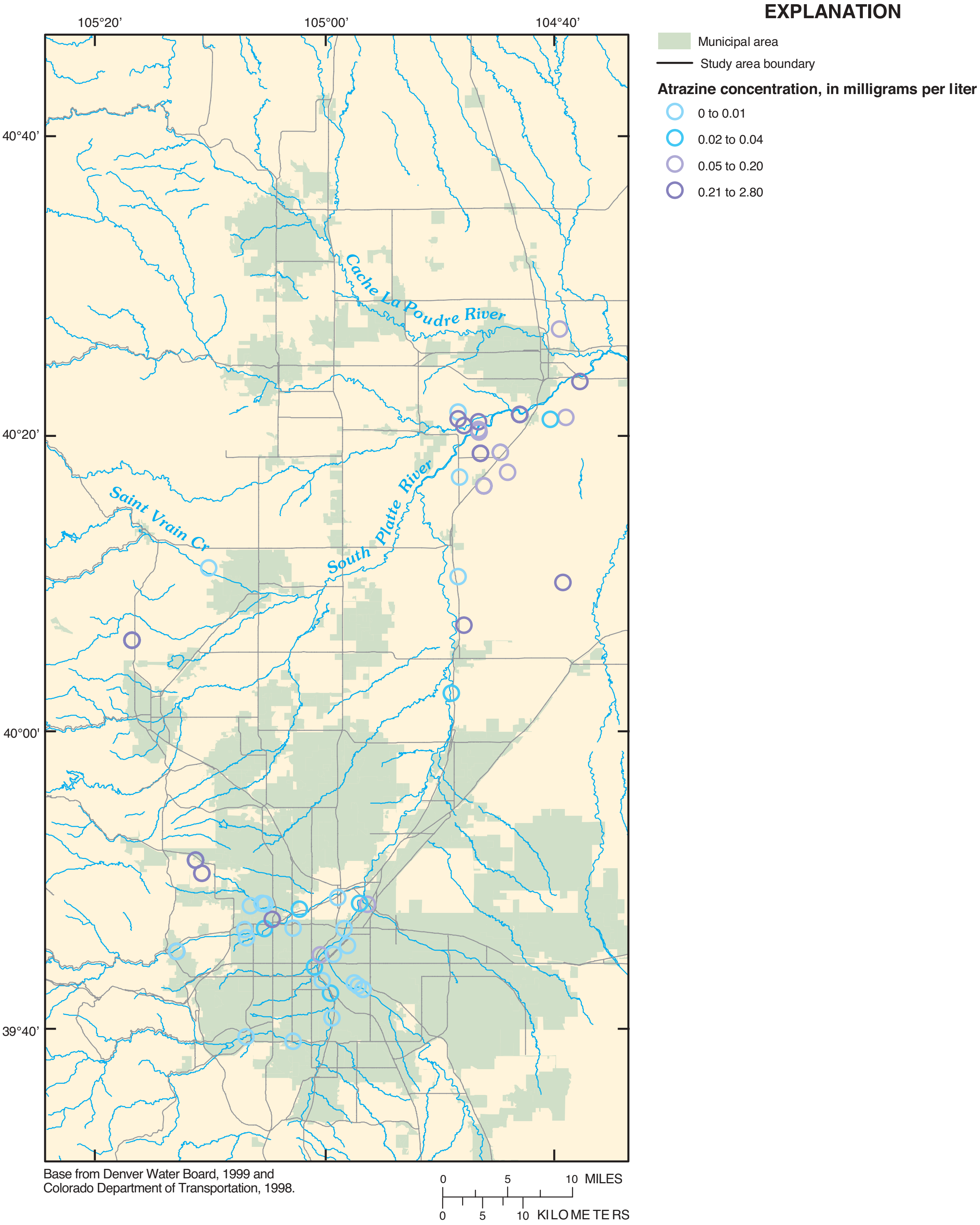
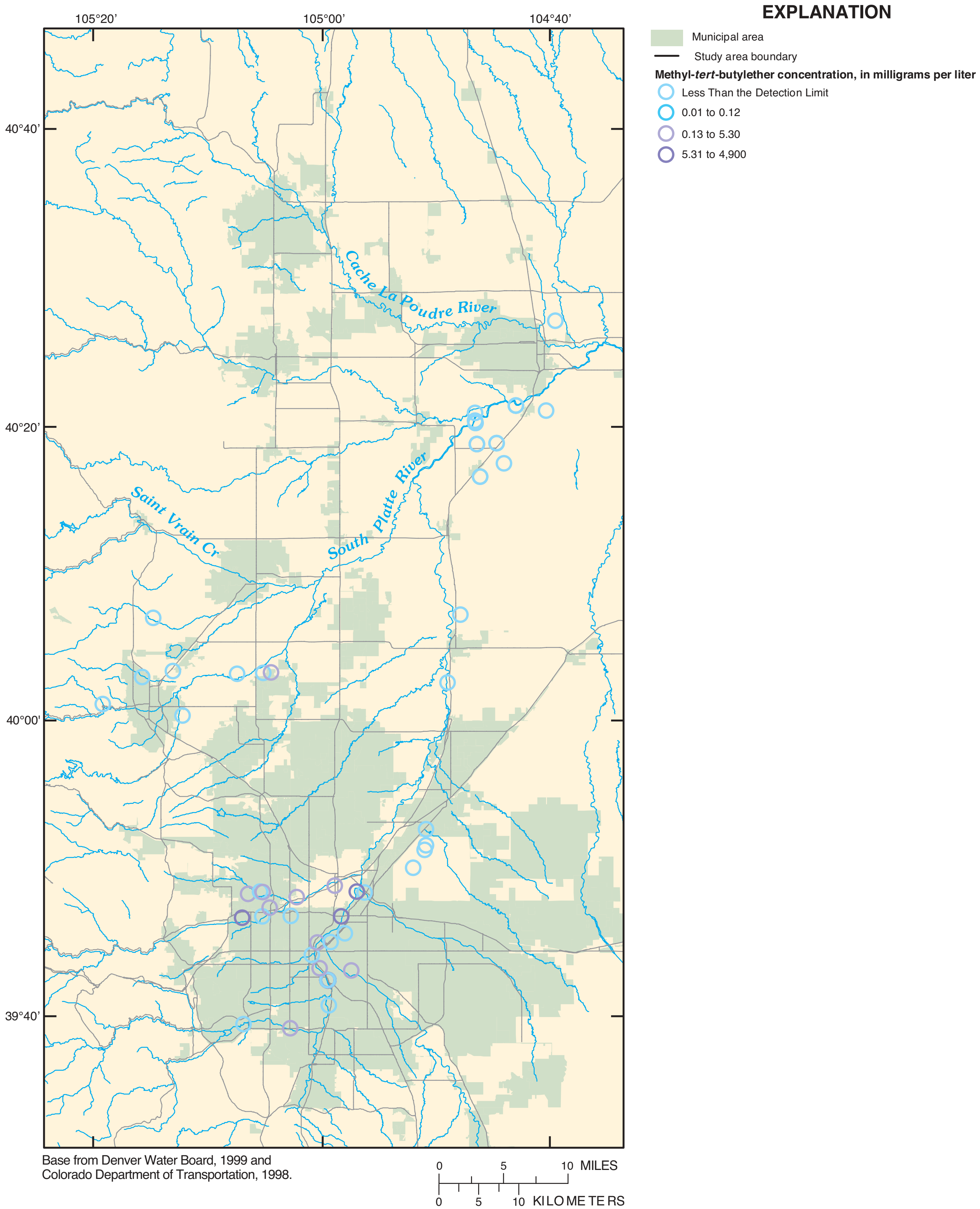
[1] Nitrite is not common in natural ground-water conditions, and nitrate plus nitrite is usually composed of all or mostly nitrate. Most samples in this database were analyzed for nitrate plus nitrite rather than for just nitrate; therefore, nitrate and nitrate plus nitrite concentrations were combined for the purpose of this study and are referred to in the text as “nitrate concentrations.



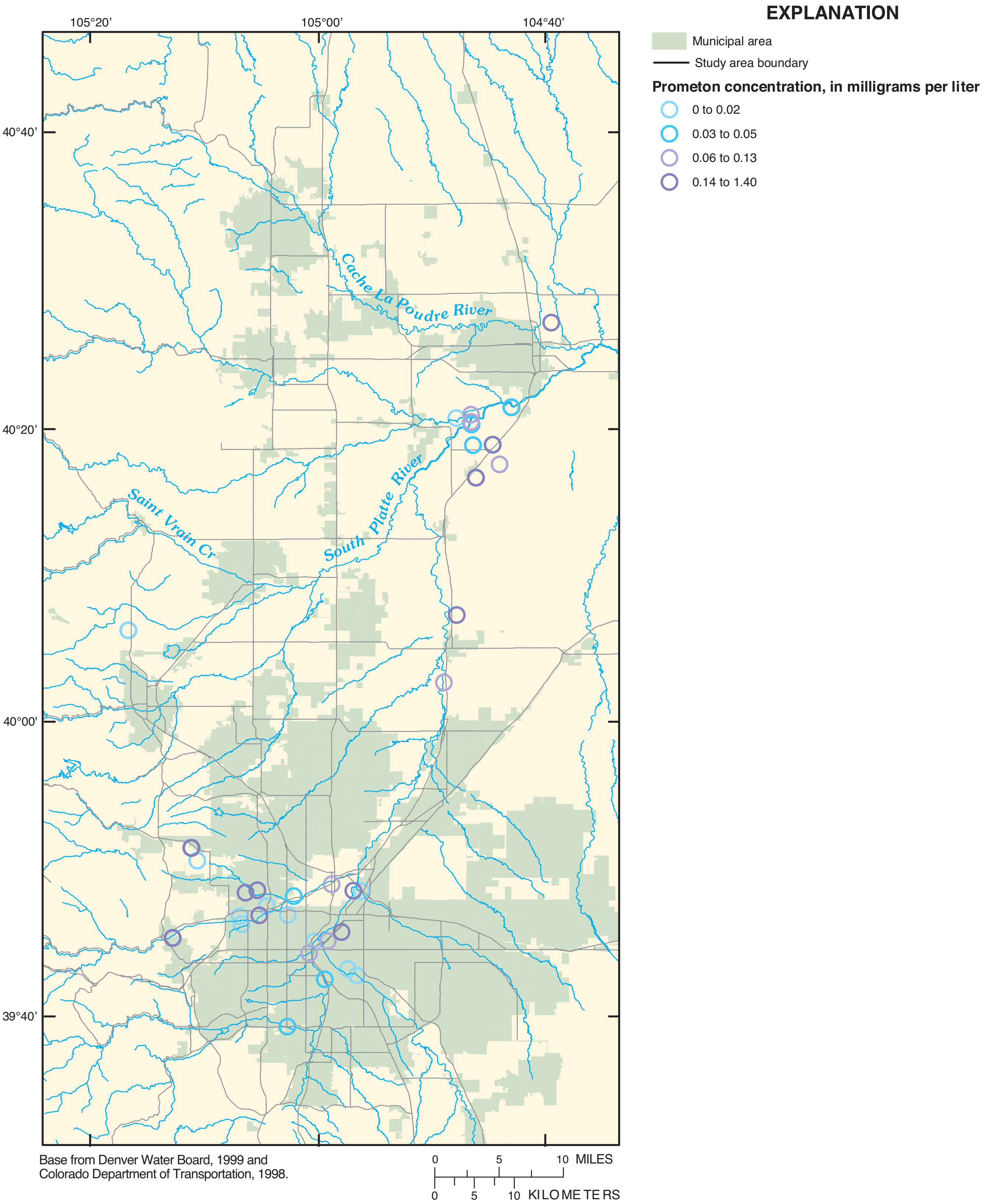
Base from Denver Water Board, 1999 and
Colorado Department of Transportation, 1998.

Figure 12. Spatial distribution of atrazine concentrations.



Base from Denver Water Board, 1999 and
Colorado Department of Transportation, 1998.

Figure 13. Spatial distribution of methyl-*tert*-butylether concentrations.



Base from Denver Water Board, 1999 and
Colorado Department of Transportation, 1998.

Figure 14. Spatial distribution of prometon concentrations.

evaluate the natural resources in the Front Range Urban Corridor that are necessary for development of infrastructure. Ground water is an infrastructure resource present in shallow aquifers and deeper bedrock aquifers that underlie the Front Range Urban Corridor. Historical (1954–98) water-quality data collected in 3,870 sampling events at 2,138 shallow ground-water wells located in the study area were used to examine concentrations of major ions, trace elements, major plant nutrients, and organic constituents.

Nonparametric summary statistics for datasets that contain data less than the detection limit were estimated using robust lognormal probability plotting for mean and standard deviation, and the adjusted lognormal maximum likelihood method for the median and quartiles. Summary statistics were calculated using conventional methods for all other data. Concentrations were mapped across the study area for specific conductance, sulfate, chloride, and nitrate. Specific-conductance data indicate that ground water in the study area included fresh to saline water. Sulfate concentrations were elevated in the north and northeast parts of the study area, possibly due to Pierre Shale and Laramie Formation shale outcrops in those areas. Areas of elevated sulfate were not coincident with areas of elevated chloride except where there is known organic contamination from waste sites. Apart from those isolated areas of known contamination, chloride concentrations were generally less than 100 mg/L across the study area. Wells with nitrate concentrations greater than 10 mg/L were usually located near rivers and streams downgradient from metropolitan areas. Elevated nitrate concentrations in wells that were not along the South Platte River were possibly from individual sewage disposal system use or from fertilizer application to land.

Spatial distribution for those organic compounds for which more than 40 percent of the data were above the detection limit (atrazine, methyl-*tert*-butylether, and prometon) is not widespread across the study area; however, not many sites were sampled for these constituents.

Summary statistics were calculated or estimated by decade and by land use for specific conductance, sulfate, chloride, and nitrate. The summary statistics by decade are influenced by the temporal variability of data across the study area. The median and interquartile range for chloride and nitrate have increased from the 1980's to the 1990's, possibly indicating greater variability across the study area in more recent years. The median values of specific conductance, chloride, and nitrate from the 1970's are less than values from the 1980's and 1990's which, because most samples from the l970's were collected in the western part of the study area, indicates that water quality of the western part of the study area is generally different than the rest of the study area. The median values of specific conductance for all land uses are similar. Chloride may be introduced to ground water from runoff of road deicers or chlorinated organics in transportation/transitional areas, where the median concentration is the greatest (85.0 mg/L). Median nitrate concentrations are several times greater where the land is cultivated or used for agricultural business, which may reflect use of nitrogen fertilizers and the presence of animal feeding operations.

Most inorganic and organic constituents exceeded drinking-water standards in only a small percentage of samples. Exceptions to this include sulfate, nitrate, and a few trace elements. Sulfate exceedances occurred in 63.4 percent of samples, nitrate exceedances in 31.9 percent of samples. Trace-element exceedances of greater than 10 percent of samples include aluminum (38.4 percent), cadmium (11.6 percent), iron (21.8 percent), and manganese (38.9 percent). Organic compounds that exceeded the drinking-water standard in more than 10 percent of the samples are 1,1-dichloroethylene (10.1 percent), tetrachloroethylene (13.1 percent), and trichloroethylene (15.7 percent). Organic compounds that exceeded the drinking-water standard in more than 5 percent of the samples are benzene (8.6 percent) and dichloromethane (6.7 percent).

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