# Shallow Ground-Water Quality of Selected Land-Use/Aquifer Settings in the South Platte River Basin, Colorado and Nebraska, 1993–95

By Breton W. Bruce and Peter B. McMahon

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# FOREWORD

The mission of the U.S. Geological Survey (USGS) is to assess the quantity and quality of the earth resources of the Nation and to provide information that will assist resource managers and policymakers at Federal, State, and local levels in making sound decisions. Assessment of water-quality conditions and trends is an important part of this overall mission.

One of the greatest challenges faced by water-resources scientists is acquiring reliable information that will guide the use and protection of the Nation's water resources. That challenge is being addressed by Federal, State, interstate, and local water-resource agencies and by many academic institutions. These organizations are collecting water-quality data for a host of purposes that include: compliance with permits and water-supply standards; development of remediation plans for specific contamination problems; operational decisions on industrial, wastewater, or water-supply facilities; and research on factors that affect water quality. An additional need for water-quality information is to provide a basis on which regional- and national-level policy decisions can be based. Wise decisions must be based on sound information. As a society we need to know whether certain types of water-quality problems are isolated or ubiquitous, whether there are significant differences in conditions among regions, whether the conditions are changing over time, and why these conditions change from place to place and over time. The information can be used to help determine the efficacy of existing water-quality policies and to help analysts determine the need for and likely consequences of new policies.

To address these needs, the U.S. Congress appropriated funds in 1986 for the USGS to begin a pilot program in seven project areas to develop and refine the National Water-Quality Assessment (NAWQA) Program. In 1991, the USGS began full implementation of the program. The NAWQA Program builds upon an existing base of water-quality studies of the USGS, as well as those of other Federal, State, and local agencies. The objectives of the NAWQA Program are to:

- Describe current water-quality conditions for a large part of the Nation's freshwater streams, rivers, and aquifers.
- Describe how water quality is changing over time.
- Improve understanding of the primary natural and human factors that affect water-quality conditions.

This information will help support the development and evaluation of management, regulatory, and monitoring decisions by other Federal, State, and local agencies to protect, use, and enhance water resources.

The goals of the NAWQA Program are being achieved through ongoing and proposed investigations of 59 of the Nation's most important river basins and aquifer systems, which are referred to as study units. These study units are distributed throughout the Nation and cover a diversity of hydrogeologic settings. More than two-thirds of the Nation's freshwater use occurs within the 59 study units and more than two-thirds of the people served by public water-supply systems live within their boundaries.

National synthesis of data analysis, based on aggregation of comparable information obtained from the study units, is a major component of the program. This effort focuses on selected water-quality topics using nationally consistent information. Comparative studies will explain differences and similarities in observed water-quality conditions among study areas and will identify changes and trends and their causes. The first topics addressed by the national synthesis are pesticides, nutrients, volatile organic compounds, and aquatic biology. Discussions on these and other water-quality topics will be published in periodic summaries of the quality of the Nation's ground and surface water as the information becomes available.

This report is an element of the comprehensive body of information developed as part of the NAWQA Program. The program depends heavily on the advice, cooperation, and information from many Federal, State, interstate, Tribal, and local agencies and the public. The assistance and suggestions of all are greatly appreciated.

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# Shallow Ground-Water Quality of Selected Land-Use/Aquifer Settings in the South Platte River Basin, Colorado and Nebraska, 1993–95

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## ABSTRACT

The occurrence and distribution of a broad range of water-quality constituents in the primary shallow ground-water aquifers in the South Platte River Basin were determined for three study areas that have specific combinations of land-use and aquifer settings: (1) Urban-crystalline bedrock, (2) urban-alluvium, and (3) agricultural-alluvium. Twenty-seven wells in the urban-crystalline bedrock study area and 30 wells in the urban-alluvium and agricultural-alluvium study areas each were sampled once for about 170 constituents, including major ions, nutrients, volatile organic compounds, pesticides, trace elements, and radon. Wells in the urban-crystalline and agricultural-alluvium study areas also were sampled for tritium. Results of water analyses indicate that natural rock/water interactions and anthropogenic land-use activities affected the quality of shallow ground water. Major-ion data indicated an increase from small concentrations of dissolved solids in the upstream urban-crystalline study area to large concentrations of dissolved solids in the downstream agricultural-alluvium study area. This downstream increase in dissolved-solids concentrations generally was correlated with a change from bicarbonate to sulfate as the dominant anion and by increasing concentrations of calcium, sodium, and sulfate. Ground water in the agricultural-alluvium study area had higher nitrate concentrations (median = 9.35 milligrams per liter as nitrogen) than the other study areas (14 of 30 samples exceeded the U.S. Environmental Protection Agency drinking-water standard of 10 milligrams per liter as nitrogen). Volatile organic compounds were detected only in water samples from the urban-crystalline and urban-alluvium study areas. Thirty-one of 59 analyzed volatile organic compounds were detected at least once in the urban-alluvium study area, and concentrations occasionally exceeded maximum contaminant levels. Pesticides were detected only in the urban-alluvium (27 of 30 wells) and agriculture-alluvium (29 of 30 wells) study areas. No measured pesticide concentration exceeded maximum contaminant levels or health advisory levels for that compound. The concentrations of the trace elements, manganese, selenium, and uranium, exceeded established or proposed drinking-water standards in one or more study areas. Background concentrations of radon in the shallow aquifers of much of the South Platte River Basin were substantially larger than the national average. The presence of recently manufactured synthetic compounds and tritium concentrations having post-1952 values indicates that the ground water being sampled in each study area recently was recharged, with the possible exception of six wells in the urban-crystalline study area that had concentrations of tritium small enough to indicate some water of pre-1952 origin.

In general, large uranium and radon concentrations occur naturally in ground water throughout the South Platte River Basin. In the urban-crystalline study area, the presence of

synthetic volatile organic compounds in ground water indicates that the crystalline bedrock aquifer is vulnerable to effects from land use. In the urban-alluvium study area, pesticides and volatile organic compounds were widespread in ground water indicating the effect of high density urban land use on water quality. In the agricultural-alluvium study area, large concentrations of dissolved solids and nitrate were measured, and pesticides frequently were detected.

# INTRODUCTION

Shallow ground-water resources are an important source of fresh water in much of the semiarid Western United States where surface-water supplies are limited. In the South Platte River Basin of Colorado, Nebraska, and Wyoming (fig. 1), extensive agricultural activities and high rates of rural and metropolitan population growth result in increased demand for development of ground-water resources. Shallow ground water (generally less than 100 ft deep) is particularly valuable because it is relatively easy to withdraw. Shallow ground water also generally is of better quality (fewer dissolved constituents) than deeper water supplies in buried aquifers.

The primary shallow aquifers in the South Platte River Basin are the fractured crystalline bedrock of Precambrian age exposed in the mountainous western part of the basin and the alluvial deposits on the eastern plains, which fill the present and historic riverbed channels. These two aquifers supply more than 95 percent of the ground water used in the South Platte River Basin (Litke, 1990). Water withdrawn from the crystalline bedrock aquifer primarily is used for domestic drinking water. Most of the water withdrawn from the alluvial aquifer is used for agricultural irrigation, and drinking water is a minor use. However, water levels are declining in parts of the deeper drinking-water aquifers under the plains (Robson, 1987), and the alluvial aquifer may become a future drinking-water supply in this part of the basin.

The shallow aquifers in the South Platte River Basin are particularly vulnerable to water-quality degradation from surface activities because of large hydraulic conductivities and the lack of a protective geohydrologic barrier between land surface and the water table. High population density and the many different intensive uses of the land in the recharge areas of these aquifers have a direct effect on ground-water quality.

Three related studies, which describe the range of ground-water-quality conditions in relatively vulnerable, unconfined aquifers beneath the major land-use settings of the South Platte River Basin, were done between 1993–95 as part of the U.S. Geological Survey's (USGS) National Water-Quality Assessment (NAWQA) program, South Platte River Basin study unit. The component of the NAWQA program that addresses the occurrence and distribution of water-quality conditions within a study unit is described in Gilliom and others (1995). The quality of shallow ground water and the effect of land use on this resource are the primary focus of the ground-water studies of the NAWQA program. These studies are designed to determine the ground-water-quality conditions underlying major land uses in the NAWQA study unit and to identify the natural and human factors affecting water quality. The studies focus on water-table aquifers because these are the most vulnerable to the effects of land-use activities.

Studies of this type provide information on the current status of water quality in these important aquifers and indicate geographical areas that have degraded water quality or are at risk of water-quality degradation. The data collected in the NAWQA program also help establish a baseline of current water-quality conditions for future comparisons. Finally, because these studies were done in areas that have well-defined land-use settings, the data can be used to better define the effects of these settings on ground-water quality and help determine changes in ground-water quality as a result of changes in land use.

## Purpose and Scope

This report presents a summary and comparison of ground-water quality in three study areas in the South Platte River Basin that have distinctive land-use settings and aquifers. The three study areas are: (1) The urban setting in the mountainous part of the basin, which had a high population density or built-up land use and a fractured crystalline bedrock aquifer (urban-crystalline study); (2) the urban setting in the Denver, Colo., metropolitan area overlying the alluvial aquifer (urban-alluvium study); and (3) the primary agricultural setting downstream from Denver to the

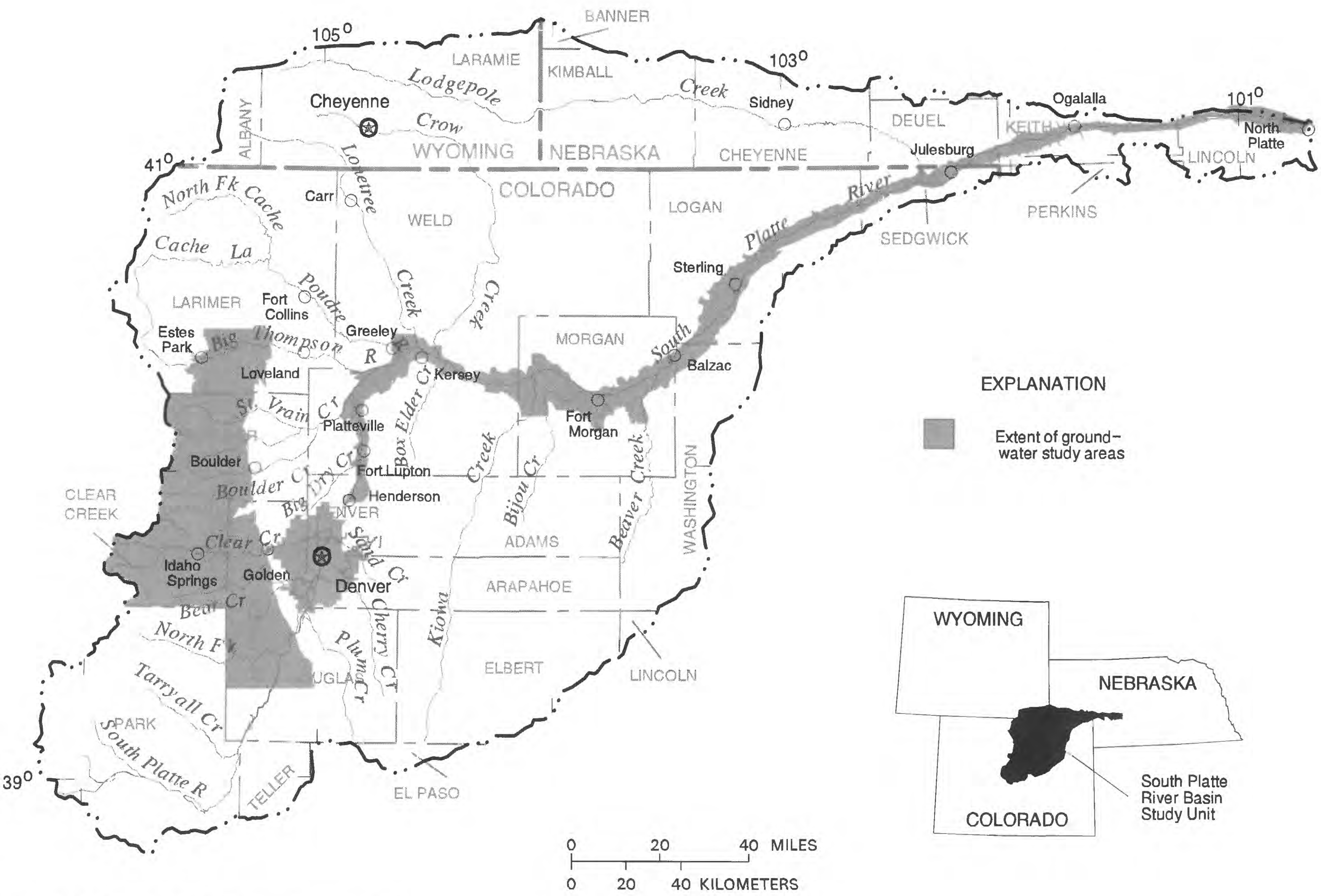


**Figure 1.** Location of the South Platte River Basin.

mouth of the basin at North Platte, Nebr., that overlies the South Platte River alluvial aquifer (agricultural-alluvium study).

The scope of the urban-crystalline study is slightly different from the two studies done in the alluvial aquifer. The complexity of ground-water flow systems in the fractured crystalline bedrock aquifer makes relating water quality to land use in close proximity to the well less certain. Water pumped from a well in this aquifer may be transported large distances through the fracture systems and, hence, not reflect local land-use effects. Twenty-seven existing wells in the urban-crystalline study were sampled once each during 1995. In the urban-alluvium study done in 1993 and the agricultural-alluvium study done in 1994, 30 wells in the alluvial aquifer were sampled one time each. The water analyses for each sampled well provide data for about 170 water-quality constituents. Constituents analyzed include major ions, nutrients, volatile organic compounds (VOC's), pesticides, trace elements, and radon.

## Acknowledgments

The number of private and public entities and the individuals that contributed to this study are far too numerous to list. The authors wish to thank all those who allowed access to their property and wells, approved new wells on their land, and who supplied information on existing wells, land use, and water quality in the South Platte River Basin. We also would like to thank the many USGS personnel, summer students, and volunteers that met well-installation and sampling deadlines. This report is a tribute to the cooperation, dedication, and good cheer of many individuals.

## AQUIFER SELECTION

The major aquifers of the South Platte River Basin are listed in table 1. Volume of ground-water withdrawal and the current level of water-quality knowledge were used as an aid to select which aquifers in the South Platte River Basin should be the focus of NAWQA investigations. Also important to the selection was the vulnerability of water quality to land-use effects. Shallow, unconfined aquifers were considered more vulnerable to land-use effects.

The crystalline bedrock aquifer in the western part of the basin was selected for study because of its use for drinking water and to provide additional water-quality information to the sparse data base. Estimated ground-water withdrawals from the crystalline bedrock aquifer (table 1) were based on county population (86,254) reported for that part of the basin (Denver Regional Council of Governments, 1993) and on the estimated percentage of the mountain population served by domestic wells in Jefferson County (Jefferson County, 1993). The estimated range of withdrawals for the crystalline bedrock aquifer was similar to the individual withdrawals from the other major drinking-water aquifers in the Denver Basin. However, with the exception of small outcrop areas near the foothills, the Denver Basin aquifers are geologically isolated from the surface and less vulnerable to water-quality effects. Although some water-quality data exist for isolated areas of the crystalline bedrock aquifer, there are no recent general studies of ground-water quality in the mountainous part of the South Platte River Basin. Historical ground-water studies generally did not include analyses for compounds such as VOC's and pesticides. This absence of water-quality data and the use of untreated drinking water by much of the mountain population led to the selection of this aquifer for inclusion in this study.

The alluvial aquifer on the plains is important because the highest volume of ground-water withdrawals in the South Platte River Basin are from this unit, there is the potential for rapid infiltration of contaminants to the ground water, and there exist several documented water-quality issues that may cause this water to be unusable in the future (Dennehy and others, 1995). This aquifer unit also is used as a drinking-water supply by some rural communities. Another important factor is that discharge from this aquifer generally is directly to surface-water bodies, primarily the South Platte River. The water quality of the alluvial aquifer affects the quality of surface water and, thus, affects aquatic life and the use and aesthetic value for people.

**Table 1.** Description of major aquifers in the South Platte River Basin

[Mgal/d, million gallons per day]

| Aquifer | Approximate withdrawal (Mgal/d) | Primary use |  | Estimated amount of water-quality data | Primary water-quality issues |
|---|---|---|---|---|---|
|  |  | Type | Percent of withdrawal |  |  |
| South Platte alluvium | [1]756 | Agriculture | 94.2 | Moderate | Nitrates, organics, metals, agrochemicals |
|  |  | Public supply | 2.7 |  |  |
|  |  | Industrial/mining | 1.7 |  |  |
|  |  | Domestic/commercial | .6 |  |  |
|  |  | Other | .8 |  |  |
| Crystalline bedrock (mountains) | [3]3.9–8.6 | Almost all domestic | 99 | Low | Nitrates, bacteria, trace elements, radon |
| Denver Basin bedrock aquifers | 23.8 | Public supply | 53.1 | Moderate | Dissolved solids |
|  |  | Agriculture | 34.4 |  |  |
| Includes: |  | Domestic/commercial | 9.4 |  |  |
| Arapahoe | ([2]12.1) | Industrial/mining | 3.1 |  |  |
| Denver | ([2]4.4) |  |  |  |  |
| Dawson | ([2]3.8) |  |  |  |  |
| Laramie/Fox Hills | ([2]3.5) |  |  |  |  |

[1] Litke (1990).

[2] Robson (1987).

[3] Estimated (60 percent of estimated population at 75 gallons per day per person-100 percent of estimated population at 100 gallons per day per person).

# HYDROGEOLOGIC CHARACTERISTICS OF AQUIFERS

## Crystalline Bedrock Aquifer

Crystalline bedrock units in the South Platte River Basin are exposed in the mountain uplifts in the western part of the basin. The Precambrian rocks of Colorado, including the crystalline bedrock units of the Front Range, have been described in some detail by Tweto (1987). The crystalline bedrock can be broadly divided into metamorphosed layered rocks and intrusive igneous rocks. The metamorphic layered rocks can be further divided into biotitic varieties, largely of metasedimentary origin, and felsic-hornblendic varieties, largely of metavolcanic origin. The metamorphic intensity generally is classified in the upper or lower amphibolite facies. The intrusive igneous rocks are mainly granite, granodiorite, or quartz-monzonite but range from syenite or gabbro to granite (Tweto, 1987).

Ground water in the crystalline bedrock aquifer is present in fault and fracture zones across the mountainous part of the basin. The predominant trend for Precambrian faults in the Front Range is north or northwest; however, faults, fractures, and joints of almost every orientation have been mapped (Tweto, 1987, pl. 1). The crystalline bedrock aquifer is characterized by small storage capacity, small yields to wells, and large fluctuations in water levels. The small volume of water in storage makes the water vulnerable to degradation because minimal dilution of contaminated infiltration is possible (Snow, 1973). Recharge to the crystalline bedrock aquifer primarily is from precipitation, and the remainder is from leach field infiltration and other household releases. Infiltration from the land surface to the water table can be relatively fast due to the high hydraulic conductivity and low storage of some fractures (Snow, 1973). Static water levels in wells commonly are a few tens of feet below land surface; however, some wells may penetrate several hundred feet of bedrock before encountering saturated fracture systems. Water then may rise in the well to levels near the ground surface. Wells in the crystalline bedrock aquifer often are drilled far below the water table to increase well-bore storage for a household reserve (Snow, 1973).

The ground-water flow system in the crystalline bedrock aquifer is poorly understood. Water withdrawn from a given well in this aquifer may have been recharged locally or some distance from the wellhead. The lack of knowledge about fracture orientation, interconnections, and local hydraulic gradients make identifying recharge areas for specific wells problematic. For the purposes of comparison in this report, it is assumed that ground water sampled in the urban-crystalline study area represents the built-up, land-use setting near the well. It is assumed that the water being sampled was recharged locally or that the land-use setting designated for the well is of large enough areal extent to encompass the recharge area for the local flow system.

## Alluvial Aquifer

The alluvial aquifer is a combination of unconsolidated sedimentary units deposited by stream aggradation that fill the current and historic incised stream channels along the valleys of the South Platte River and its tributaries. These sediments predominantly range from upper Pleistocene to upper Holocene in age. Alluvial units form terraces and flood plains of gravel, sand, silt, and clay as high as 40 ft above the present (1995) stream level and extend locally to as deep as 290 ft below the stream level (Bjorklund and Brown, 1957). The thickest alluvial deposits occur mainly in the eastern part of the basin. The alluvial deposits generally are coarse-grained, cobbly gravels near the mountains to the west (which were the source for most of the sediments) and become finer grained to the east, although local lenses of very coarse gravels occur in the eastern part of the basin. Granitic rock fragments make up more than one-half of the alluvium; the other materials are quartz, welded tuff, ironstone, chert, mica, and pieces of other rock fragments, particularly quartzitic sandstone (Scott, 1963). In places, calcium carbonate and silt cement the sediments into friable sands. Iron- and manganese-oxide staining is common, and strongly developed soil horizons have been formed locally within the sediments. The largest boulders are in the lower alluvial units and are as much as 18 in. in diameter. Much of the bedrock underlying the alluvial aquifer is of low hydraulic conductivity and acts as an effective confining unit to vertical ground-water flow.

Hydraulic properties of the alluvial aquifer are highly variable because of changes in grain size, distribution of clay lenses, and aquifer thickness. Reported porosity ranges are from 20 to 40 percent, and hydraulic conductivities are reported from 100 to 2,000 ft/d for sands and gravels in this aquifer (Robson, 1989). Estimated average hydraulic conductivity for the alluvial aquifer along the South Platte River near Denver is 870 ft/d (Robson, 1989). Depth to water in the alluvial aquifer ranges from zero to about 40 ft, and annual fluctuations in water levels of more than 15 ft have been observed in heavily irrigated areas. Recharge to the alluvial aquifer is from precipitation and irrigation with surface water. At a few points along the South Platte River, almost the entire flow is diverted for irrigation on the alluvial aquifer. Discharge from the alluvial aquifer generally is to surface-water bodies. Hydraulic gradients generally are toward the river, intersecting the river at an angle in a downstream direction. Base flow in the South Platte River in the eastern basin is almost entirely from surface- and ground-water return flows as a result of irrigation (Litke, 1996).

# DESCRIPTION OF STUDY AREAS AND LAND USE/LAND COVER

## Urban-Crystalline Study

The study area in the mountainous part of the South Platte River Basin, where shallow ground-water quality in the crystalline bedrock aquifer was evaluated, is shown in figure 2. Areas include the western parts of Jefferson and Boulder Counties, the south-central mountainous section of Larimer County (extending about 5 mi north of Estes Park, Colo., and excluding Rocky Mountain National Park), and the entire areas of Gilpin and Clear Creek Counties. Within this 1,720-mi$^2$ study area are scattered pockets of urban land use as defined by Fegeas and others (1983). These built-up areas were the focus of the urban-crystalline study.

The urban areas in the mountains are dominated by residential housing developments (mainly single-family homes) and occasional commercial developments. Mountain urban areas have increased in size

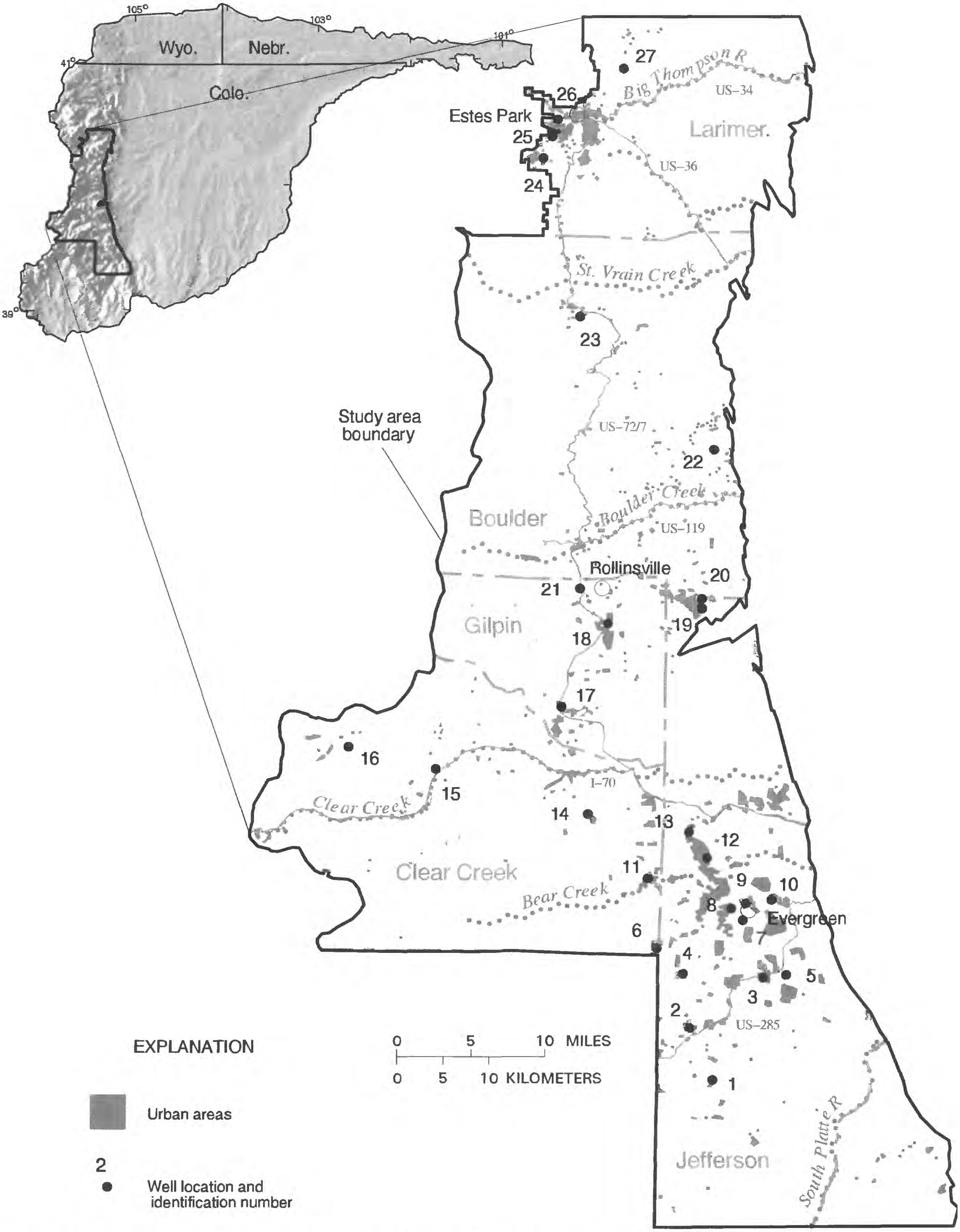


**Figure 2.** Location of urban-crystalline study area in the South Platte River Basin, urban/built-up land-use areas and sampled wells.

since data were collected by Fegeas and others (1983) in 1977. Between 1970 and 1990, the population of the mountainous part of Jefferson County increased from 17,308 to 43,228; an increase of about 250 percent (Jefferson County, 1993). The Denver Regional Council of Governments (1993) calculated a Jefferson County mountain population of 55,200 for 1993. By using the Fegeas and others (1983) digital coverage to aid in selecting well locations, the urban-crystalline study focused on the oldest and largest urbanized areas in the mountainous part of the basin. Fegeas and others (1983) indicated that the combined area of urban land usage within the mountain study area was 55.6 mi$^2$ or about 3 percent of the total study area.

Anderson Level II land-cover designations (Anderson and others, 1976) within 1/4 mi of each well sampled in the urban-crystalline study were determined from Fegeas and others (1983). The land-cover designations assigned by Fegeas and others (1983) are summarized in table 2. For example, 11 of 27 wells in the urban-crystalline study had land-cover designated as barren land within a 1/4-mi radius. For those 11 wells, the median percentage of barren land-cover within 1/4 mi was 13 percent. The USGS assessed land cover during 1995 by using a combination of onsite observations, well owner interviews, and a review of 1995 aerial photography acquired from the Jefferson County GIS Department, Golden, Colo., and 1994 aerial photography from the U.S. Forest Service, Rocky Mountain Regional Office, Denver, Colo. Housing density determined from aerial photographs provides a more accurate indication of 1995 urban/built-up land-use conditions near the sampled wells. The median number of houses within a 1/4-mi radius of the wells sampled in the urban-crystalline study area was 32; the maximum number of houses within a 1/4-mi radius was 197. Of the 27 wells sampled, 3 were in developments served by public sewer systems.

The climatic conditions in the mountainous part of the South Platte River Basin are characterized by cooler average temperatures and greater precipitation totals than occur on the plains. Temperature and precipitation ranges correlate well with changes in elevation and are reflected in the four main north-south-trending vegetative belts on the eastern slope of the Rocky Mountain Front Range: the lower montane forest, upper montane forest, subalpine forest, and alpine tundra vegetative zones. Barry (1972) summarized climatic conditions for weather monitoring stations in each of these zones in the Front Range eastern slope for 1952–70. The National Oceanic and Atmospheric Administration (1994) reported 1994 temperatures in the mountain study area ranging from –21°F (Mt. Evans Research Station, January 1994, elevation 10,630 ft) to 88°F (Evergreen, Colo., July 1994, elevation 7,000 ft). Precipitation generally increases with elevation from an annual average of about 20 in. at low elevations to more than 40 in. near the Continental Divide. Much of the precipitation at the higher elevations is in the form of snow that accumulates during winter and remains stored until spring melt, beginning in May.

Population estimated for the entire 1,720-mi$^2$ mountain study area in 1993 was about 90,000 people (Denver Regional Council of Governments, 1993). Jefferson County Planning and Zoning Department (1993) estimated that 52 percent of the Jefferson County mountain population was supplied by individual wells. An even greater percentage of the population have individual septic disposal systems. Jefferson County mountain communities have a

**Table 2.** Minimum, median, and maximum percentage of land-cover types within 1/4-mile-radius of wells sampled in the urban-crystalline study area

[Fegeas and others, 1983; numbers in parentheses indicate wells having identified land cover within 1/4 mile]

| Land-cover type | Minimum percentage | Median percentage | Maximum percentage |
|---|---|---|---|
| Barren land (11 wells) | 1 | 13 | 77 |
| Forest (25 wells) | 4 | 46 | 100 |
| Rangeland (6 wells) | 4 | 23 | 33 |
| Transportation (1 well) | 9 | 9 | 9 |
| Tundra (1 well) | 65 | 65 | 65 |
| Urban (23 wells) | 2 | 41 | 100 |

greater number of public water and sanitation facilities than other parts of the study area. If an estimated 60 to 70 percent of all mountain households are supplied by well water, this equates to about 54,000 to 63,000 people drinking water directly from this aquifer.

Because well production in the crystalline bedrock aquifer generally is small, most homes use low-water, natural landscaping techniques. Unlike suburban areas in Denver, bluegrass lawns and gardens are uncommon. Therefore, it is expected that the use of lawn fertilizers and lawn herbicides also is less than in the urban areas of Denver.

Individual septic disposal systems are used by most private residences in the mountains. Individual septic disposal systems are a potential source of nitrates, phosphates, and other constituents in household wastewater to the ground-water system.

Water-quality constituents derived from natural rock/water interactions also are a concern in the mountain study area. Specific trace elements and radon gas from minerals in the crystalline bedrock are known to be present at high concentrations in ground water (Lawrence and others, 1991; Folger and others, 1994).

## Urban-Alluvium Study

The setting for the urban-alluvium study was the Denver metropolitan area (fig. 3), which consisted of the city of Denver and 15 other organized city districts that cover an area of about 300 mi$^2$ (Fegeas and others, 1983). Denver was incorporated as a city in 1861 and is one of the major centers of commerce and industry along the eastern flank of the Rocky Mountains. The estimated population within this area in 1992 was 1.7 million (Colorado Demographer's Office, 1992).

The physical environment in Denver is a semiarid, high plains setting with an elevation of about 1 mi above sea level. Temperatures range from –30 to 100°F, and average annual precipitation is less than 15 in. A detailed review of the environmental setting of the South Platte River Basin study area is in Dennehy and others (1993).

The extent of the alluvial deposits within the Denver metropolitan area also is shown in figure 3. The urban-alluvium study area boundary was defined by the extent of alluvial deposits, as determined by Trimble and Machette (1979), along the South Platte River and major tributary streams within the Denver metropolitan area. This study area is about 75 mi$^2$ in size, or 25 percent of the Denver metropolitan area.

Detailed land-use/land-cover information for the urban-alluvium study area was acquired from the U.S. Environmental Protection Agency (EPA) Ecosystem Protection and Remediation Office, Region 8, Denver, Colo. This digital land-use/land-cover map is in the form of a Geographic Information System (GIS) ARC/INFO (Environmental Systems Research Institute, 1987) coverage and was based on an interpretation of 1992 SPOT satellite imagery with field verification (Rodrigo, 1994). A summary of Anderson Level II land-use/land-cover categories identified in this digital coverage for the urban-alluvium study area is listed in table 3. Residential and commercial settings comprise more than 50 percent of the land cover in the EPA's interpretation of the data. Industrial land comprises only 6 percent of the study area. Open and undeveloped lands are classified as cropland and pasture in table 3 and account for 12 percent of the land cover in the study area. The amount of undeveloped land has continued to decrease since the satellite images were taken; mostly being converted to residential land use. The category, other urban or built-up, includes parks and golf courses under the EPA's classification scheme. The land-use settings mentioned above comprise more than 80 percent of the EPA's digital land cover in the urban-alluvium study area.

The USGS made onsite determinations of land use at each sampled well based on visual observation of land use within 100 ft of the well at the time of sampling. For the USGS determinations, residential settings included single-family homes, apartment complexes, parks, and golf courses. Commercial settings were defined as shopping malls, restaurants, nonmanufacturing business areas, gas stations, and other customer-service establishments. Industrial settings were those areas where active material or chemical manufacturing was taking place. Of the 30 wells sampled in the urban-alluvium study area, 12 were determined to be in residential settings, 12 in commercial settings, and 6 in industrial settings.

The release of synthetic chemicals and household waste to the environment in the urban-alluvium study area is poorly documented. Much of the waste generated by human sources in the Denver metropolitan area is collected and disposed of through public or

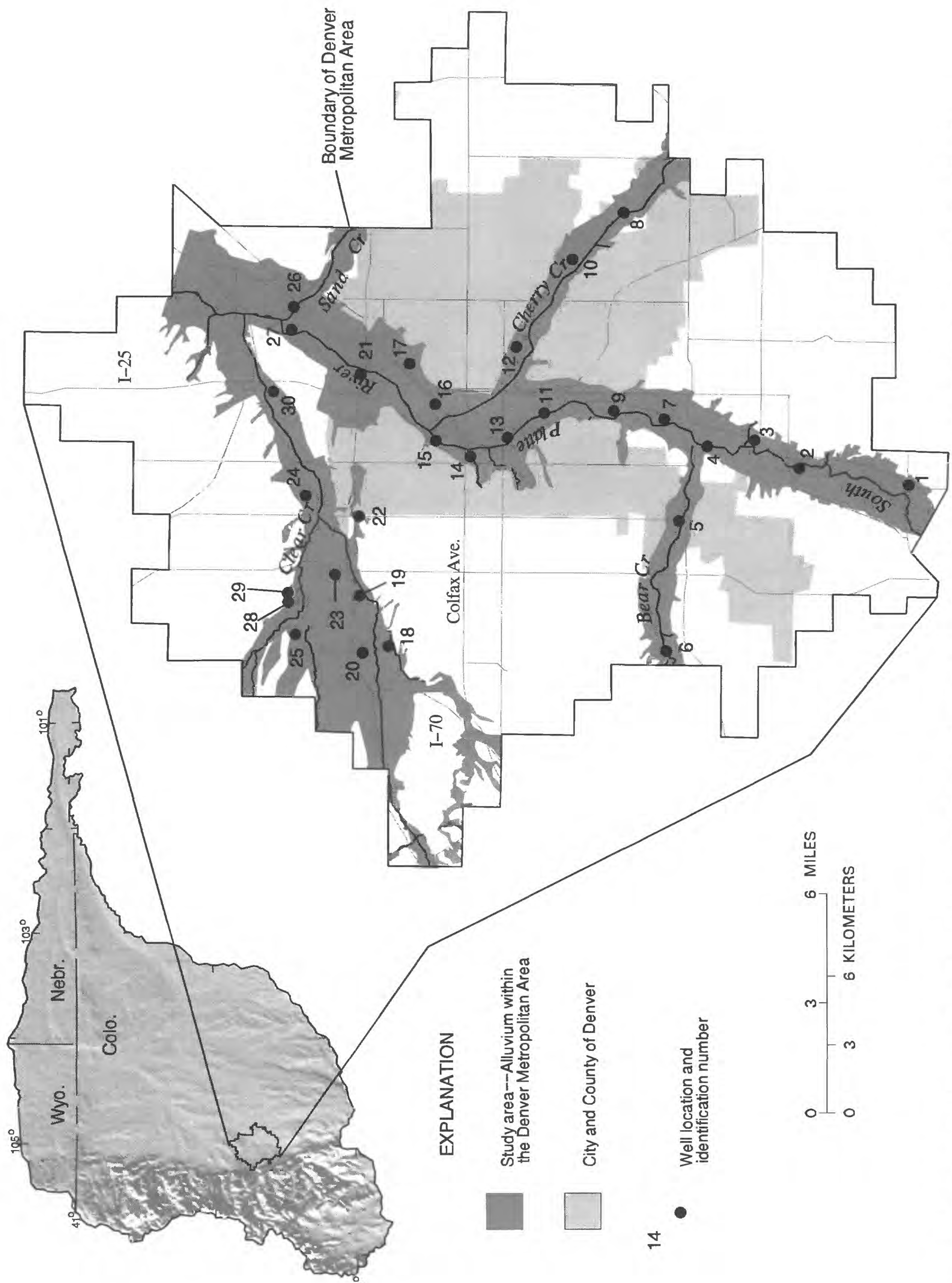


**Figure 3.** Location of urban-alluvium study area (metropolitan Denver, Colorado) in the South Platte River Basin, alluvial deposits, and sampled wells.

**Table 3.** Anderson Level II (Anderson and others, 1976) land-use and land-cover classifications and percentage of each land-cover classification in the urban-alluvium study area

| Anderson Level II land-use and land-cover classification | [1]Percentage of land-cover classification in study area |
|---|---|
| Residential | 32 |
| Commercial and services | 22 |
| Cropland and pasture (includes open and undeveloped land) | 12 |
| Other urban or built-up | 9 |
| Industrial | 6 |
| Strip mines, quarries, gravel pits | 5 |
| Mixed urban or built-up | 3 |
| Transportation, communications, and utilities | 2 |
| Transitional areas | 1 |
| Reservoirs | 1 |
| Orchards, groves, vineyards, nurseries, and ornamentals | 1 |
| Other agricultural land | 1 |
| Herbaceous rangeland | .4 |
| Shrub and brush rangeland | .3 |
| Mixed rangeland | .2 |
| Lakes | .2 |
| Forested wetland | .1 |
| Sandy areas other than beaches | .1 |
| Confined feeding operations | .04 |
| Unclassified | 3.66 |

[1] Rodrigo, 1994; total area of Denver metropolitan alluvial study, about 75 square miles.

private entities. Solid waste generally is disposed of by collection and controlled landfill operations. Public and individual recycling efforts also handle a part of this waste stream. The primary method for disposal of wastewater and organic solids is by sewage-collection systems and wastewater-treatment facilities.

An informal survey of owners of large landscaped areas, commercial landscape services, and lawn and garden retail outlets in the cities of Greeley, Fort Collins, and Loveland, Colo. (all within the South Platte River Basin), was done in 1994–95. This survey estimated an average application rate of 153 lb of nitrogen fertilizer per acre per year to turf areas in these cities (Dave Dubois, Northern Front Range Water Quality Planning Association, written commun., 1995).

The release of synthetic VOC's into the urban environment is possible from wherever these types of compounds are used or stored. The Colorado Department of Revenue reports, on a monthly basis, the total gallons of gasoline and specialty fuels distributed and taxed in the State of Colorado and the total retail sales (in dollars) for gas stations in the State, by county (Heidi Vach, Colorado Department of Revenue, written commun., 1995). Using this information (and the fact that about 52 percent of the State's population lives in the Denver metropolitan area), it was estimated that more than 1.06 billion gallons of fuel were used in the Denver metropolitan area during 1992. The EPA's Toxics Release Inventory (TRI) data base (U.S. Environmental Protection Agency, 1995) reports the release of hazardous or toxic chemicals into the air, water, or land of the Nation's communities. In the Denver metropolitan area in 1993, the year of the urban-alluvium study, 56 compounds were reported as having at least one release. For these 56 compounds, there were a total of 253 releases.

Pesticide-use information in urban areas of the South Platte River Basin was compiled by Kimbrough and Litke (in press). They reported the pesticides most commonly used in urban areas of the South Platte River Basin by commercial applicators, golf courses, highway maintenance departments, or large urban landowners (table 4) and the pesticides most commonly available to the public at lawn and garden stores in the Denver metropolitan area (table 5). Several pesticides used in urban areas, such as chlorpyrifos, carbaryl, 2,4-D, DCPA, dicamba, malathion, and prometon, also are used in agricultural areas and cannot be attributed to a single land use. The large amount of VOC's and pesticides stored and used in this study area make it likely that these constituents will be present in the shallow ground water.

## Agricultural-Alluvium Study

The agricultural-alluvium study area is shown in figure 4. The primary irrigated agricultural section of the South Platte River Basin coincides with the availability of surface- and ground-water supplies. The alluvial aquifer provides the large well yields necessary for irrigation; consequently, the boundary of the agricultural-alluvium study area was defined using the boundaries of the alluvial aquifer. The study area is adjacent to the South Platte River from Fort Lupton,

**Table 4.** Pesticides most commonly used in urban areas of the South Platte River Basin by commercial applicators, golf courses, highway maintenance departments, or large urban land owners

[From Kimbrough and Litke, in press]

| Herbicides | | | Insecticides |
|---|---|---|---|
| Bromacil | Imazapyr | Prometon | Bifenthrin |
| Clopyralid | MCPA | Tebuthiuron | Carbaryl |
| Dicamba | Oryzalin | Triclopyr | Chlorpyrifos |
| Diuron | Picloram | Trifluralin | Diazinon |
| Glyphosate | Prodiamine | 2,4-D | Pyrethroids |

Colo., downstream to the mouth of the basin at North Platte, Nebr. The study area is about 1,180 mi$^2$ (755,200 acres) spread out along about 300 river miles. The population in this area generally is concentrated in the larger community centers. These communities usually are served by waste-collection and treatment facilities that handle solid waste and wastewater. Most of the land area outside of these communities is irrigated agriculture with single-family farm houses scattered between crop fields. Most single-family farms use septic/leach-field systems to treat household wastewater. Rangeland also is common. The agricultural-alluvium study area receives slightly more precipitation (about 16+ in/yr) than the urban-alluvium area, and precipitation increases with distance away from the mountains. The area is considered to have a continental-type climate (Dennehy and others, 1993). Temperature extremes are similar to the urban-alluvium study area and range from –30 to 110°F.

Detailed information on agricultural production for the agricultural-alluvium study area was not available because statistics are kept on a county basis, and the limit of the study area does not conform to these geopolitical boundaries. Irrigated crop acreage was estimated from the Colorado, Nebraska, and Wyoming Agricultural Statistics Service data bases from 1987 to 1994. Total irrigated acreage in the South Platte River Basin varied from 800,000 acres to 960,000 acres (David Litke, U.S. Geological Survey, written commun., 1996). Fegeas and others (1983) identify 783 mi$^2$ (501,102 acres) of the agricultural-alluvium study area (66.4 percent) as cropland. Cropping patterns and the ranking of crops in the South Platte River Basin remain fairly consistent over time. Corn was the major crop grown in the study area in 1994 (about 57 percent of harvested acres) followed by alfalfa hay, dry beans, sugar beets, sunflowers, and barley. Potatoes, onions, oats, sorghum, and miscellaneous vegetables also were grown in smaller amounts. Most of the vegetables are grown near Greeley, Colo., in the western part of the study area; corn is predominant in the eastern part of the basin. Annual crop rotation is common in the study area, and most of the common crops require irrigation.

**Table 5.** Pesticides most commonly available to the public at lawn and garden stores in the Denver metropolitan area

[from Kimbrough and Litke, in press]

| Herbicides | Insecticides |
|---|---|
| DCPA | Carbaryl |
| Glyphosate | Chlorpyrifos |
| Trifluralin | Diazinon |
| 2,4-D | Malathion |

Data from Fegeas and others (1983) were used to determine land use/land cover within a 1/4-mi radius of the wells sampled in the agricultural-alluvium study area. These data are summarized in table 6. Of the 30 wells sampled, 25 had more than 80 percent cropland within a 1/4-mi radius. The remaining land generally was wetlands with minor transportation, rangeland, and urban lands. Interviews with owners of the land at the well sites indicated that crops grown near the wells were consistent with those identified in the county agricultural statistics, mainly corn, alfalfa hay, and beans. Irrigation of fields near the sampled wells primarily was from ground water with only a few land owners reporting surface-water sources.

The presence of fertilizers and pesticides in the alluvial ground water of the South Platte River Basin has been documented previously (Schuff, 1992; Dennehy and others, 1995). Total volume and rates of application for fertilizers and pesticides in the basin are poorly documented, but are somewhat crop

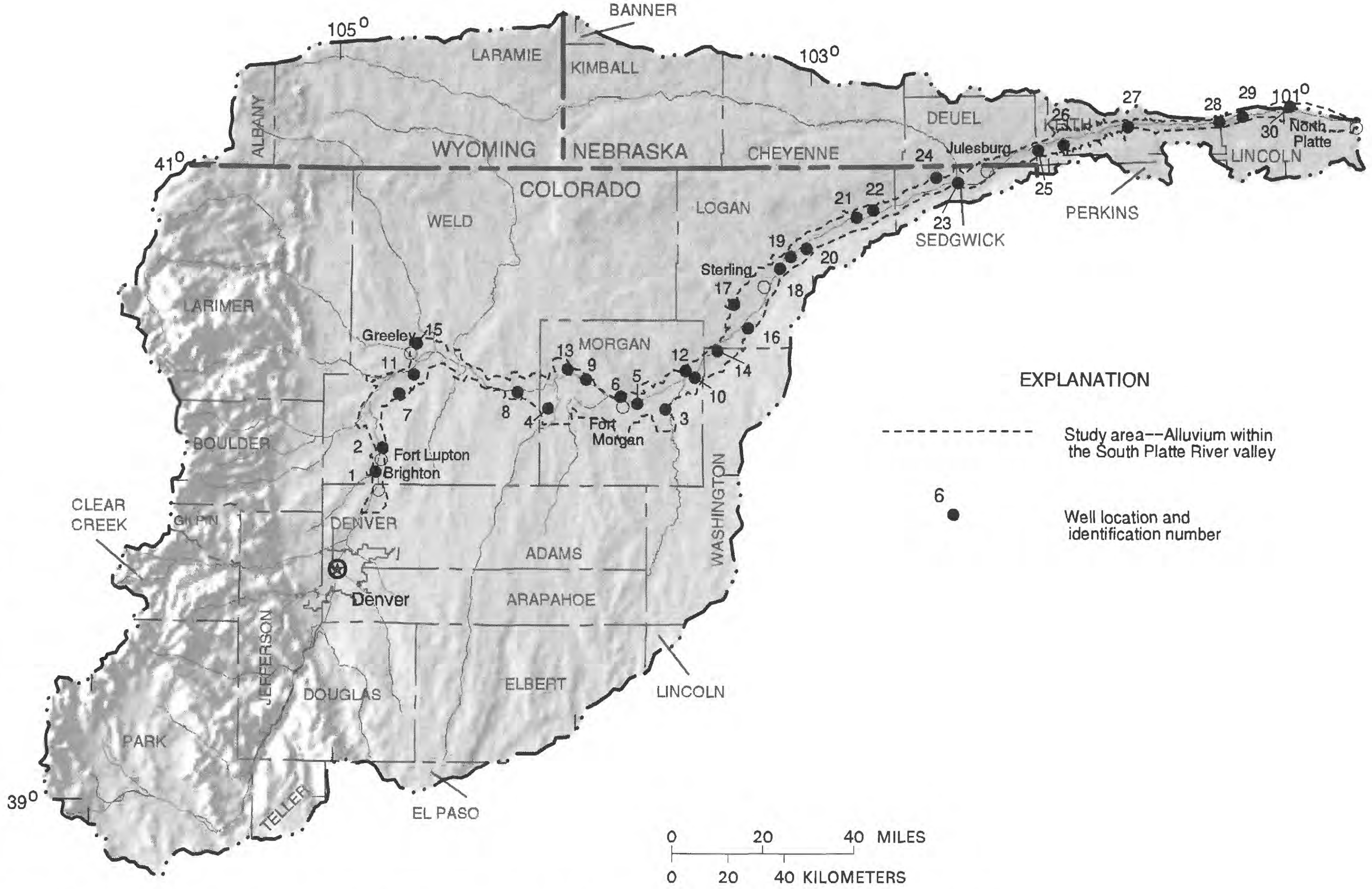


**Figure 4.** Location of agricultural-alluvium study area in the South Platte River Basin, alluvial deposits, and sampled wells.

**Table 6.** Anderson Level II (Anderson and others, 1976) land-use and land-cover classifications and percentage of each land-cover classification in the agricultural-alluvium study area

| Anderson Level II land-use and land-cover classification | [1]Percentage of land-cover classification in study area |
|---|---|
| Cropland and pasture | 67 |
| Mixed rangeland | 10 |
| Forested wetland | 8 |
| Herbaceous rangeland | 7 |
| Reservoirs | 2 |
| Transportation, communications, and utilities | 1.4 |
| Residential | 1.2 |
| Nonforested wetland | .8 |
| Confined feeding operations | .6 |
| Commercial and services | .6 |
| Mixed urban or built-up | .3 |
| Other urban or built-up | .2 |
| Strip mines, quarries, or gravel pits | .1 |
| Industrial | .1 |
| Sandy areas other than beaches | .1 |
| Orchards, groves, vineyards, nurseries, and ornamentals | .04 |
| Shrub and brush rangeland | .04 |
| Transitional areas | .04 |
| Unclassified | .48 |

[1] From Fegeas and others, 1984; total area of the agricultural-alluvium study area, approximately 1,180 square miles.

specific. Corn, the predominant crop in the study area, commonly is fertilized with nitrogen at an average rate of 150 to 180 lb/acre of nitrogen. Many of the other crops grown in the basin also require nitrogen fertilizer. Nitrogen usually is applied in the form of anhydrous ammonia or manure.

Four pesticides—atrazine, cyanazine, metolachlor, and EPTC—are applied to corn fields almost everywhere in the agricultural-alluvium study area. Other pesticides with more crop-specific applications may be limited to that part of the study area where the crop is primarily grown. An example would be the onion pesticide DCPA, which is applied more frequently in the western part of the study area where most onions are produced. Dennehy and others (1995, p. 17) list the 10 most commonly applied insecticides and herbicides in the South Platte River Basin and provide values for pounds of active ingredient applied. Many of these compounds are used for several crops and have widespread application in the basin.

The use and storage of VOC's in the agricultural-alluvium study area is minimal relative to the large size of the study area. Oil and gas exploration and production is a land-use activity in the basin that is a potential source for these compounds. Cappa and Tremain (1994) report that the Denver Basin's Wattenberg oil field was one of the most active for exploration in the United States in 1993. The high level of exploration prompted the Colorado Oil and Gas Conservation Commission to implement restrictive Wattenberg field rules throughout Weld County, Colo., in 1994, which mandated casing protection for all freshwater aquifers in the Denver Basin through the depth of the Fox Hills Sandstone of Cretaceous age. This protective measure is not always practiced throughout the rest of the study area.

# METHODS OF INVESTIGATION

## Well Selection

To obtain a statistically valid representation of ground-water quality in the three study areas, well sites were selected for sampling using a computerized technique that generated a network of randomly distributed potential sampling locations (Scott, 1990). The program divides a digital GIS polygon coverage of a study area into a predetermined number of equal-area blocks and then randomly selects sampling sites from a dense population of equally spaced nodes in each block. The target number of sampling sites for each study area was 30. In each study area, 30 primary and 30 secondary potential sampling sites were selected. Permission was acquired to install water-quality monitoring wells or to sample acceptable existing wells as close as possible to the computer-generated sites. A well was considered acceptable if detailed well-construction information was available including, at a minimum, well depth and screened interval. Sampling access to well water upgradient from any pressure tank or holding tank also was required. Wells screened near the water table were chosen for this study. Detailed procedures for selection, installation, and documentation of wells sampled under the NAWQA program are described in Lapham and others (1995).

In the urban-crystalline study area, the extent of exposed crystalline bedrock aquifer was first cross-referenced with a digital coverage of urban land use as defined by Fegeas and others (1983). The choice to focus on urban areas that overlie the crystalline bedrock aquifer was because (1) the urban or built-up areas were where the aquifer was being used as a drinking-water supply, (2) existing wells were to be sampled and the urban areas were the location of most existing wells; to install wells in the crystalline bedrock aquifer was cost prohibitive, and (3) the effect of urban land use on ground-water quality in the crystalline bedrock aquifer was poorly understood.

The 27 wells sampled in the urban-crystalline study area were all in continuous service as a public or domestic water supply. These wells were identified using the records of the Colorado Department of Natural Resources, State Engineers Office. When possible, the well that was sampled was the shallowest well on record that was located within the same 1-mi$^2$ section as the site chosen randomly by the computer. Difficulties in contacting part-time residents forced the sampling of the second or third shallowest wells in some areas. Static water levels for the wells sampled in the urban-crystalline study were not available because the wells were in continuous operation, and the well bore was not readily accessible. Most wells in the urban-crystalline study area were constructed with short near-surface steel casings and then had open-hole or perforated plastic casings through the productive interval to the bottom of the hole. Water generally was delivered to the user from submersible electric pumps placed at the bottom of the wells. The distribution of wells sampled in the urban-crystalline study area is shown in figure 2.

In the urban-alluvium study, existing wells were located and sampled. Of the 30 wells sampled, 23 were constructed using polyvinyl chloride (PVC) casings, and 7 were constructed using metal casings. Existing urban wells had been installed to measure ground-water levels (3 wells), determine random ground-water quality (14 wells), provide a residential water supply (7 wells), or determine ground-water quality upgradient from a site known to have chemical contamination (6 wells). If a well had been installed at a known contaminated site, it was selected for sampling only if sufficient water-table data were available to demonstrate that it was upgradient from the known point source. None of the wells sampled in the urban-alluvium study area were currently being used for drinking water. The distribution of wells sampled in the urban-alluvium study area is shown in figure 3.

All 30 wells sampled in the agricultural-alluvium study area were installed for the purpose of water-quality monitoring. Twenty-five of these wells were installed specifically for this study. Installations were as close as possible to the locations chosen by the site-selection computer program and generally less than 1/2 mi from the preselected location. The remaining five wells existed prior to the study and were within 1 mi of the randomly chosen sites. All wells in the agricultural-alluvium study area were constructed using PVC casings and sanitary installation techniques (Lapham and others, 1995). The distribution of wells sampled in the agricultural-alluvium study area is shown in figure 4. A summary of well construction information for all the wells sampled in each of the three water-quality studies is listed in table 7.

**Table 7.** Well information for all wells sampled in three study areas in the South Platte River Basin, 1993–95

[depths, lengths, and intervals in feet; --, no data; PVC, polyvinyl chloride]

| Well number | Site ID | Well depth | Water level | Screened interval | Casing material | Water use | Sampling date |
|---|---|---|---|---|---|---|---|
| **Urban-Crystalline Study Area** | | | | | | | |
| 1 | 392646105193701 | 300 | -- | 220–280 | Steel/PVC | Domestic | 08/22/95 |
| 2 | 392947105212601 | 400 | -- | 160–370 | Steel/Plastic | Public | 08/22/95 |
| 3 | 393245105155000 | 125 | -- | 65–125 | Steel/Plastic | Domestic | 09/11/95 |
| 4 | 393256105215901 | 225 | -- | 125–225 | Steel/Plastic | Domestic | 08/23/95 |
| 5 | 393257105140301 | 305 | -- | 10–305 | Steel/Plastic | Domestic | 08/24/95 |
| 6 | 393422105240101 | 202 | -- | 82–182 | Steel/PVC | Domestic | 08/23/95 |
| 7 | 393604105172701 | 180 | -- | 140–180 | Steel/Plastic | Domestic | 08/23/95 |
| 8 | 393644105182101 | 100 | -- | 27–100 | Steel/Open | Domestic | 08/16/95 |
| 9 | 393703105171501 | 202 | -- | 82–202 | Steel/Plastic | Domestic | 08/24/95 |
| 10 | 393717105151701 | 330 | -- | 20–330 | Steel/Open | Domestic | 08/16/95 |
| 11 | 393827105244701 | 152 | -- | 90–110<br>130–152 | Steel/PVC | Domestic | 08/16/95 |
| 12 | 393941105201701 | 185 | -- | 80–185 | Steel/Plastic | Domestic | 08/15/95 |
| 13 | 394112105214201 | 65 | -- | 20–65 | Steel/Open | Domestic | 08/15/95 |
| 14 | 394210105292901 | 280 | -- | 95–105<br>130–140<br>235–275 | Steel/Plastic | Domestic | 08/24/95 |
| 15 | 394437105411301 | 200 | -- | 60–200 | Steel/Plastic | Domestic | 07/24/95 |
| 16 | 394548105475801 | 200 | -- | 49–53<br>160–200 | Steel/Plastic | Public | 07/24/95 |
| 17 | 394820105313801 | 250 | -- | 130–230 | Plastic | Domestic | 07/25/95 |
| 18 | 395314105281001 | 180 | -- | 120–180 | Steel/Plastic | Domestic | 07/25/95 |
| 19 | 395411105205601 | 250 | -- | 15–250 | Steel/Open | Domestic | 07/26/95 |
| 20 | 395445105205801 | 350 | -- | 90–110<br>190–210<br>328–350 | Steel | Domestic | 07/26/95 |
| 21 | 395516105302201 | 400 | -- | 200–400 | Steel/PVC | Domestic | 07/26/95 |
| 22 | 400324105201201 | 300 | -- | 140–200<br>220–280 | Steel/PVC | Domestic | 08/17/95 |
| 23 | 401104105304301 | 163 | -- | 20–163 | Steel/Open | Domestic | 07/27/95 |
| 24 | 402015105334601 | 200 | -- | 20–200 | Steel/Open | Domestic | 08/14/95 |
| 25 | 402131105330601 | 300 | -- | 240–300 | Steel/PVC | Domestic | 07/27/95 |
| 26 | 402231105324201 | 400 | -- | 280–300<br>360–400 | Steel/PVC | Domestic | 07/27/95 |
| 27 | 402530105273901 | 265 | -- | 15–265 | Steel/Plastic | Domestic | 08/14/95 |
| **Urban-Alluvium Study Area** | | | | | | | |
| 1 | 393357105020201 | 26.5 | 18.01 | 15–25 | PVC | Unused | 07/15/93 |
| 2 | 393632105013201 | 41 | 9.74 | 21–41 | PVC | Unused | 08/04/93 |
| 3 | 393736105004001 | 20 | 15.45 | 10–20 | PVC | Unused | 07/29/93 |
| 4 | 393843105005201 | 19 | 8.44 | 4–19 | PVC | Unused | 08/04/93 |
| 5 | 393922105031201 | 24 | 14.92 | 9–24 | PVC | Unused | 08/11/93 |
| 6 | 393938105071401 | 14 | 8.83 | 9–14 | PVC | Unused | 07/15/93 |
| 7 | 393944105000201 | 23 | 15.11 | 8–23 | PVC | Unused | 07/29/93 |
| 8 | 394044104533901 | 37 | 11.41 | 10.5–37 | PVC | Unused | 080/3/93 |
| 9 | 394056104594801 | 45 | 8.97 | 25–45 | Steel | Domestic | 08/19/93 |
| 10 | 394056104550701 | 70 | 12.56 | 11–66 | PVC | Unused | 08/03/93 |
| 11 | 394234104595301 | 30 | 15.13 | 10–30 | PVC | Unused | 08/05/93 |
| 12 | 394314104575001 | 30 | -- | 20–30 | Steel | Domestic | 08/19/93 |
| 13 | 394326105003901 | 28 | 13.05 | 12.5–27.5 | PVC | Unused | 08/05/93 |

**Table 7.** Well information for all wells sampled in three study areas in the South Platte River Basin, 1993–95—Continued

[depths, lengths, and intervals in feet; --, no data; PVC, polyvinyl chloride]

| Well number | Site ID | Well depth | Water level | Screened interval | Casing material | Water use | Sampling date |
|---|---|---|---|---|---|---|---|
| **Urban-Alluvium Study Area—Continued** | | | | | | | |
| 14 | 394418105011501 | 31 | 16.78 | 10–30.25 | PVC | Unused | 07/22/93 |
| 15 | 394507105004601 | 15 | 10.44 | 3.3–12.6 | PVC | Unused | 07/22/93 |
| 16 | 394508104593801 | 23 | 13.98 | 12–22 | PVC | Unused | 07/21/93 |
| 17 | 394545104582301 | 46 | 37.05 | 26–46 | PVC | Unused | 07/21/93 |
| 18 | 394612105071001 | 40 | -- | 20?–40 | Steel | Domestic | 08/18/93 |
| 19 | 394648105072301 | 21.5 | 4.51 | 4.5–19.5 | PVC | Unused | 07/14/93 |
| 20 | 394631105053601 | 25 | 6.15 | 12–25 | Steel | Domestic | 08/12/93 |
| 21 | 394654104584301 | 35 | 14.49 | 9.5–34.5 | PVC | Unused | 07/20/93 |
| 22 | 394655105030901 | 14.8 | 5.15 | 3–12 | PVC | Unused | 07/20/93 |
| 23 | 394728105045801 | 25 | 6.62 | 4–19 | PVC | Unused | 07/14/93 |
| 24 | 394811105023201 | 15 | 9.2 | 5–15 | PVC | Unused | 07/13/93 |
| 25 | 394824105065001 | 51 | 19.39 | 10–51 | Steel | Unused | 08/12/93 |
| 26 | 394830104564001 | 24 | 22.08 | 14–24 | PVC | Unused | 08/13/93 |
| 27 | 394833104572201 | 20 | 14.97 | 15–20 | PVC | Unused | 07/23/93 |
| 28 | 394834105055001 | 30 | 19.51 | 18–30 | Steel | Unused | 09/09/93 |
| 29 | 394835105053301 | 80 | 19.32 | 20–65 | Steel | Unused | 09/09/93 |
| 30 | 394858104591701 | 32 | 9.21 | 6.5–31.5 | PVC | Unused | 07/30/93 |
| **Agricultural-Alluvium Study Area** | | | | | | | |
| 1 | 400237104500301 | 12.5 | 9.97 | 7.5–12.5 | PVC | Unused | 06/08/94 |
| 2 | 400711104481801 | 31 | 22.60 | 21–31 | PVC | Unused | 06/08/94 |
| 3 | 401440103373201 | 23 | 11.95 | 13–23 | PVC | Unused | 07/20/94 |
| 4 | 401449104064801 | 93 | 84.92 | 83–93 | PVC | Unused | 07/26/94 |
| 5 | 401544103443101 | 47 | 35.00 | 37–47 | PVC | Unused | 07/21/94 |
| 6 | 401702103483901 | 31 | 26.12 | 21–31 | PVC | Unused | 07/21/94 |
| 7 | 401726104442201 | 26 | 19.60 | 16–26 | PVC | Unused | 06/09/94 |
| 8 | 401750104143101 | 38 | 29.15 | 28–38 | PVC | Unused | 07/26/94 |
| 9 | 402018103571801 | 13 | 4.26 | 7–12 | PVC | Unused | 07/25/94 |
| 10 | 402034103301001 | 23 | 13.19 | 13–23 | PVC | Unused | 07/19/94 |
| 11 | 402104104404501 | 19 | 12.62 | 5.5–19 | PVC | Unused | 06/09/94 |
| 12 | 402150103322801 | 27 | 21.88 | 17–27 | PVC | Unused | 07/20/94 |
| 13 | 402213104015501 | 12 | 5.23 | 5–12 | PVC | Unused | 07/25/94 |
| 14 | 402538103242001 | 20 | 10.77 | 10–20 | PVC | Unused | 07/19/94 |
| 15 | 402658104400001 | 33 | 26.89 | 18–33 | PVC | Unused | 06/10/94 |
| 16 | 402955103163501 | 36 | 22.30 | 26–36 | PVC | Unused | 07/18/94 |
| 17 | 403426103200401 | 31 | 25.85 | 21–31 | PVC | Unused | 07/18/94 |
| 18 | 404106103082201 | 18 | 6.13 | 8–18 | PVC | Unused | 08/04/94 |
| 19 | 404320103053801 | 17 | 8.58 | 7–17 | PVC | Unused | 08/03/94 |
| 20 | 404450103013501 | 47 | 41.11 | 37–47 | PVC | Unused | 08/03/94 |
| 21 | 405039102485601 | 15 | 7.33 | 5–15 | PVC | Unused | 08/02/94 |
| 22 | 405159102444201 | 15 | 11.38 | 5–15 | PVC | Unused | 0802/94 |
| 23 | 405658102231201 | 16 | 8.71 | 6–16 | PVC | Unused | 08/01/94 |
| 24 | 405801102284501 | 30 | 20.34 | 20–30 | PVC | Unused | 08/01/94 |
| 25 | 410251102024201 | 22 | 13.85 | 12–22 | PVC | Unused | 06/16/94 |
| 26 | 410344101560901 | 33 | 19.27 | 23–33 | PVC | Unused | 06/16/94 |
| 27 | 410657101394501 | 17 | 11.59 | 7–17 | PVC | Unused | 06/15/94 |
| 28 | 410722101162901 | 22 | 13.56 | 12–22 | PVC | Unused | 06/15/94 |
| 29 | 410819101102801 | 17 | 8.19 | 7–17 | PVC | Unused | 06/14/94 |
| 30 | 410959100582401 | 23 | 9.48 | 13–23 | PVC | Unused | 06/14/94 |

## Sample Collection

Each well was sampled for a broad range of dissolved constituents including 11 major ions, 5 nutrients, 59 VOC's, 76 pesticides, 17 trace elements, radon, dissolved organic carbon and, in the urban-crystalline and agricultural-alluvium studies, tritium. The constituents analyzed in each of these classes are listed in table 8. In wells with pumps that were in continuous use, the existing pumps were used to collect the water-quality samples. Existing pumps were used in 3 urban-alluvium wells and in all 27 wells sampled in the urban-crystalline study area. In the remaining wells, a portable positive-displacement submersible pump was used for sample collection. This pump was constructed so that all parts that came in contact with well water were stainless steel or Teflon. The pump was decontaminated prior to placement in each well by circulating a nonphosphate detergent through the pump system, followed by a tap-water rinse, deionized water rinse, methanol rinse, and final deionized water rinse.

Prior to sample collection, each well was purged by pumping at the highest rate possible (usually greater than 5 gal/min) for at least 20 minutes. After initial well purging, the pumping rate was decreased, and temperature, pH, specific conductance, and dissolved oxygen (DO) were monitored and recorded every 5 minutes. In wells where the existing pump was used to collect the sample, the flow from the existing pump was split into two streams so that flow rate could be adjusted in one stream while the pumping pressure could be accommodated in the other. Once a minimum of five well-casing volumes had been removed and the indicated field parameters had stabilized for three 5-minute increments, the water was collected for laboratory analysis.

A detailed description of NAWQA ground-water sampling protocols is in Koterba and others (1995). Dissolved major-ion and trace-element samples included filtered (0.45-µm cellulose-nitrate filters) and unfiltered samples, and the cation species were stabilized by lowering the pH to less than 2 standard units using nitric acid. Samples for dissolved nutrient analyses were filtered through 0.45-µm cellulose-nitrate filters and were preserved, using mercuric chloride, in amber polyethylene bottles. The nutrient samples then were stored at 4°C until analyzed. Unfiltered VOC samples were preserved using 1:1 hydrochloric acid in 40-mL septum vials leaving no headspace. The pesticide samples were filtered through a cleaned and baked 0.7-µm glass-fiber filter in a methanol-rinsed aluminum filter holder and collected in precleaned 1-L amber glass bottles. For radon analysis, two 10-mL aliquots of water were collected by syringe from a flow-through glass gas-sampling bulb. This water was injected into glass scintillation vials below mineral oil; the vials were capped and shaken vigorously for 15 seconds. Tritium samples were composed of an unfiltered 1-L sample collected in a high density polyethylene bottle and sealed with a polyseal cap with no headspace. Alkalinity was determined in the field by titration. All other laboratory analyses were done at the USGS National Water-Quality Laboratory in Arvada, Colo.

**Table 8.** Water-quality constituents and parameters analyzed by compound class for three study areas in the South Platte River Basin, 1993–95

[µg/L, micrograms per liter; pCi/L, picocuries per liter; mg/L, milligrams per liter]

| Constituent | Analytical method reporting limit | Constituent | Analytical method reporting limit |
|---|---|---|---|
| **Major ions, in milligrams per liter (unless noted)** | | | |
| Calcium | 0.02 | Silica | 0.01 |
| Magnesium | .01 | Iron | 3.0 µg/L |
| Sodium | .2 | Manganese | 1.0 µg/L |
| Potassium | .1 | Bromide | .01 |
| Chloride | .1 | Sum of dissolved solids | calculated |
| Sulfate | .1 | Hardness | calculated |
| Fluoride | .1 | | |
| **Nutrients, in milligrams per liter** | | | |
| Ammonium | 0.01 | Phosphorus | 0.01 |
| Nitrite | .01 | Orthophosphate | .01 |
| Nitrite plus nitrate | .05 | | |
| **Volatile Organic Compounds, in micrograms per liter** | | | |
| Benzene | 0.2 | Dichloroethene, Trans- | 0.2 |
| Bromobenzene | .2 | Dichloroethylene | .2 |
| Bromoform | .2 | Dichlorofluoromethane | .2 |
| Butylbenzene, N- | .2 | Dichloropropane | .2 |
| Butylbenzene, Sec- | .2 | Dichloropropane, 1,3- | .2 |
| Butylbenzene, Tert- | .2 | Dichloropropane, 2,2- | .2 |
| Carbontetrachloride | .2 | Dichloropropene, 1,1- | .2 |
| Chlorobenzene | .2 | Freon 113 | .2 |
| Chlorobenzene, O- | .2 | Hexachlorobutadiene | .2 |
| Chlorodibromomethane | .2 | Isopropylbenzene | .2 |
| Chloroethane | .2 | Isopropyltoluene, P- | .2 |
| Chloroform | .2 | Mesitylene | .2 |
| Chlorotoluene, O- | .2 | Methylbromide | .2 |
| Chlorotoluene, P- | .2 | Methylchloride | .2 |
| Dibromochloropropane | .2 | Methylenechloride | .2 |
| Dichloropropene, Cis-1,3- | .2 | Methyltertbutylether | .2 |
| Dibromoethane, 1,2- | .2 | Naphthalene | .2 |
| Dibromomethane | .2 | Propylbenzene, N- | .2 |
| Dichloropropene, Trans-1,3- | .2 | Pseudocumene | .2 |
| Ethylbenzene | .2 | Styrene | .2 |
| Dichlorobenzene, 1,3- | .2 | Tetrachloroethane, 1,1,1,2- | .2 |
| Dichlorobenzene, 1,4- | .2 | Tetrachloroethane, 1,1,2,2- | .2 |
| Dichlorobromomethane | .2 | Tetrachloroethylene | .2 |
| Dichloroethane, 1,1- | .2 | Toluene | .2 |
| Dicholoroethane, 1,2- | .2 | Trichlorobenzene, 1,2,3- | .2 |
| Dichloroethene, Cis-1,2- | .2 | Trichlorobenzene, 1,2,4- | .2 |

**Table 8.** Water-quality constituents and parameters analyzed by compound class for three study areas in the South Platte River Basin, 1993–95—Continued

[µg/L, micrograms per liter; pCi/L, picocuries per liter; mg/L, milligrams per liter]

| Constituent | Analytical method reporting limit | Constituent | Analytical method reporting limit |
|---|---|---|---|
| **Volatile Organic Compounds, in micrograms per liter—Continued** | | | |
| Trichloroethane, 1,1,1- | 0.2 | Trichloropropane, 1,2,3- | 0.2 |
| Trichloroethane, 1,1,2- | .2 | Vinylchloride | .2 |
| Trichloroethylene | .2 | Xylene | .2 |
| Trichlorofluoromethane | .2 | | |
| **Pesticides, in micrograms per liter** | | | |
| 2,4-D | 0.035 | Ethalfluralin | 0.013 |
| 2,4-DB | .035 | Ethoprop | .012 |
| 2,4,5-T | .035 | Fenuron | .013 |
| 2,4,5-TP | .05 | Fluometuron | .035 |
| 3-OH-Carbofuran | .014 | Fonofos | .008 |
| Acifluorfen | .035 | Lindane | .011 |
| Alachlor | .009 | Linuron | .018 |
| Aldicarb Sulfoxide | .021 | Malathion | .01 |
| Alpha BHC | .007 | MCPA | .05 |
| Atrazine | .017 | Methomyl | .017 |
| Benfluralin | .013 | Methylazinphos | .038 |
| Bentazon | .014 | Methylparathion | .035 |
| Bromacil | .035 | Metolachlor | .009 |
| Bromoxynil | .035 | Metribuzin | .012 |
| Butylate | .008 | Molinate | .007 |
| Carbaryl | .046 | Napropamide | .01 |
| Carbofuran | .028 | Neburon | .015 |
| Chloramben | .011 | Norflurazon | .024 |
| Chlorpyrifos | .005 | Oryzalin | .019 |
| Clopyralid | .05 | Parathion | .022 |
| Cyanazine | .013 | Pebulate | .009 |
| Deethylatrazine | .02 | Pendimethalin | .018 |
| DCPA | .004 | Permethrin | .016 |
| DDE,P,P' | .01 | Phorate | .02 |
| Diazinon | .008 | Picloram | .05 |
| Dicamba | .035 | Prometon | .008 |
| Dichlobenil | .02 | Pronamide | .009 |
| Dichlorprop | .032 | Propachlor | .015 |
| Dieldrin | .02 | Propanil | .016 |
| Diethylanalin | .006 | Propargite | .01 |
| Dinoseb | .035 | Propham | .035 |
| Disulfoton | .02 | Propoxur | .035 |
| Diuron | .02 | Simazine | .01 |
| DNOC | .035 | Terbufos | .012 |
| EPTC | .005 | Tebuthiuron | .015 |
| Esfenvalerate | .019 | Terbacil | .03 |

**Table 8.** Water-quality constituents and parameters analyzed by compound class for three study areas in the South Platte River Basin, 1993–95—Continued

[µg/L, micrograms per liter; pCi/L, picocuries per liter; mg/L, milligrams per liter]

| Constituent | Analytical method reporting limit | Constituent | Analytical method reporting limit |
|---|---|---|---|
| | **Pesticides, in micrograms per liter—Continued** | | |
| Thiobencarb | .008 | Triclopyr | 0.05 |
| Triallate | .008 | Trifluralin | .012 |
| | **Trace elements, in micrograms per liter** | | |
| Aluminum | 1.0 | Lead | 1.0 |
| Antimony | 1.0 | Manganese | 1.0 |
| Arsenic | 1.0 | Molybdenum | 1.0 |
| Barium | 1.0 | Nickel | 1.0 |
| Beryllium | 1.0 | Selenium | 1.0 |
| Cadmium | 1.0 | Silver | 1.0 |
| Chromium | 1.0 | Uranium | 1.0 |
| Cobalt | 1.0 | Zinc | 1.0 |
| Copper | 1.0 | | |
| | **Other constituents** | | |
| Radon | 24.0 pCi/L | Tritium | 2.5 pCi/L |
| Dissolved organic carbon | .2 mg/L | | |

## QUALITY-CONTROL SAMPLES

Quality-control samples for each of the three ground-water studies included equipment/field blank samples, replicate samples, and matrix spike recovery and spike replicate sample experiments. About 30 percent of the samples analyzed during the three ground-water studies were quality-control samples: 10 percent were blanks, 10 percent were ground-water replicates, and 10 percent were matrix spikes.

Blank samples provided verification that decontamination of sampling equipment was adequate and that field procedures did not contaminate samples. Blank samples were collected for major ions, nutrients, VOC's, two separate pesticide analytical methods—gas chromatography/mass spectrometry (GC/MS) (Zaugg and others, 1995) and high-performance liquid chromatography (HPLC) (Werner and others, 1995)—and trace elements. Blank samples consisted of quality-assured organic-free or inorganic-free water, which was passed through all sampling equipment (including filters) and collected in a manner similar to that used to collect the environmental water-quality samples. Those constituents detected in blank samples are listed in table 9. No pesticide compounds were detected in blank samples.

Replicate samples were collected to assess the combined effects of field and laboratory procedures on measurement variability. Replicate samples were collected directly following, and in the same manner as, the samples for analyses of major ions, nutrients, both pesticide methods, trace elements, radon, and tritium. The relative percent difference (RPD) between replicate analyses was calculated using the formula:

RPD = absolute value {(Sample 1 - Sample 2)/
[(Sample 1 + Sample 2)/2]} * 100.

**Table 9.** Constituents detected in quality-assurance blank samples

[mg/L, milligrams per liter; µg/L, micrograms per liter]

| Constituent | Number of detections/ number of samples | Median concentration in blank samples | Maximum concentration in blank samples |
|---|---|---|---|
| | **Major ions (in mg/L)** | | |
| Alkalinity (as $CaCO_3$) | 10/10 | 1.6 | 1.7 |
| Calcium | 7/10 | 0.08 | 0.29 |
| Chloride | 2/10 | <0.1 | 0.2 |
| Magnesium | 1/10 | <0.01 | 0.01 |
| Potassium | 1/10 | <0.1 | 1.4 |
| Silica | 7/10 | 0.02 | 0.05 |
| Sodium | 1/10 | <0.2 | 0.3 |
| Sulfate | 2/10 | <0.1 | 0.2 |
| | **Nutrients (in mg/L)** | | |
| Ammonium | 4/9 | 0.02 | 0.04 |
| | **Volatile organic compounds (in µg/L)** | | |
| Chloroform | 3/9 | <0.2 | 0.2 |
| Methylene chloride | 3/9 | <0.2 | 0.4 |
| | **Trace elements (in µg/L)** | | |
| Aluminum | 10/10 | 4 | 7 |
| Copper | 1/10 | <1 | 1 |
| Manganese | 2/10 | <1 | 8 |
| Molybdenum | 1/10 | <1 | 1 |
| Nickel | 1/10 | <1 | 2 |
| Silver | 1/10 | <1 | 1 |
| Zinc | 7/10 | 2 | 13 |

The RPD can be calculated only for compounds that were detected above the method reporting limit (MRL) in replicate samples. An RPD of 200 percent will occur when one sample has a very low concentration and the other a nondetection (for example, Sample 1 = 0.01 µg/L, Sample 2 = 0.00 µg/L).

Replicate samples also were collected for the pesticide field matrix spike samples. The purpose of field matrix spike samples was to assess the recovery bias and variability in recovery of the spiked constituents in relation to different ground-water matrices. Field matrix spikes (mixtures of multiple known compounds dissolved in methanol) were added at known concentrations to randomly selected well water samples for VOC's and the two pesticide analytical methods. Replicate spikes were produced for each of the pesticide samples; however, no replication of VOC spikes was performed. Statistical results for environmental sample replication, field matrix spike recoveries, and field matrix spike replication are listed in table 10. High RPD's listed in table 10 generally are for constituents with concentrations close to the analytical MRL. Information on the median percent recoveries for each of the compounds in the VOC and pesticide spike mixtures are listed in table 11.

**Table 10.** Percentage of recoveries for field matrix spike analytes and relative percent differences (RPD's) for replicate samples

[Count, for spike recoveries indicates total number of compounds injected for all spike samples; for replicate samples indicates number of compounds with replicate pairs]

| Compound class | Percentile | | | | | Count | Minimum | Maximum |
|---|---|---|---|---|---|---|---|---|
| | 10 | 25 | 50 | 75 | 90 | | | |
| | **Field matrix spike recoveries (in percent)** | | | | | | | |
| Volatile organic compounds | 53.8 | 60.9 | 70.0 | 81.8 | 95.7 | 130 | 45.4 | 354.5 |
| Pesticide SH-2001 | 52.7 | 67.3 | 86.7 | 100.7 | 115.3 | 648 | 10.5 | 455.0 |
| Pesticide SH-2050 | 25.6 | 50.9 | 74.0 | 93.5 | 117.9 | 284 | 0.0 | 248.6 |
| | **Field matrix spike replication (relative percent difference in percent)** | | | | | | | |
| Volatile organic compounds | (1) | (1) | (1) | (1) | (1) | (1) | (1) | (1) |
| Pesticide SH-2001 | 0.6 | 2.1 | 4.4 | 7.8 | 13.4 | 279 | 0.0 | 200 |
| Pesticide SH-2050 | 1.1 | 3.6 | 11.2 | 30.5 | 52.3 | 122 | 0.1 | 200 |
| | **Environmental sample replication (relative percent difference in percent)** | | | | | | | |
| Major ions | 0.0 | 0.0 | 0.0 | 2.2 | 5.7 | 153 | 0.0 | 200 |
| Nutrients | 0.0 | 0.0 | 0.0 | 0.0 | 28.6 | 54 | 0.0 | 200 |
| Trace elements | 0.0 | 0.0 | 0.0 | 9. | 66.7 | 153 | 0.0 | 200 |
| Radon | 0.0 | 3.2 | 4.2 | 7.2 | 8.9 | 8 | 0.0 | 8.7 |
| Tritium | 0.0 | 0.0 | 6.0 | 12.1 | 17.4 | 6 | 0.0 | 17.4 |
| Dissolved organic carbon | 0.0 | 0.0 | 35. | 100 | 121 | 8 | 0.0 | 200 |
| Volatile organic compounds | (2) | (2) | (2) | (2) | (2) | (2) | (2) | (2) |
| Pesticide SH-2001 | (3) | (3) | (3) | (3) | (3) | (3) | (3) | (3) |
| Pesticide SH-2050 | (4) | (4) | (4) | (4) | (4) | (4) | (4) | (4) |

[1] No replication of spike samples.

[2] No replication of environmental samples.

[3] Seven replicated detections; relative percent differences = 5.7, 6.1, 6.4, 13.9, 15.4, 18.2, 42.8.

[4] No detections in environmental samples.

**Table 11.** Median percent recoveries for individual compounds in volatile organic and pesticide field spike mixtures

| Compound | Percent recovery | Compound | Percent recovery |
|---|---|---|---|
| **Volatile organic compounds** | | | |
| Methyl tert-butyl ether | 80 | 1,2 Dichloroethane | 80 |
| 1,4 Dichlorobenzene | 75 | Bromoform | 75 |
| Chlorodibromomethane | 73 | Trichloroethane | 71 |
| Dichlorobromomethane | 71 | Trichloroehtylene | 70 |
| Tetracholoroehtylene | 68 | Ethylbenxene | 68 |
| Dichloroehtylene | 65 | Vinylchloride | 63 |
| Carbontetrachloride | 55 | | |
| **Pesticide compounds (by GC/MS)** | | | |
| Carbaryl | 119 | Carbofuran | 108 |
| DCPA | 103 | Napropamide | 102 |
| Metolachlor | 100 | Linuron | 99 |
| Terbufos | 95 | Alachlor | 95 |
| Atrazine | 95 | Parathion | 93 |
| Chlorpyrifos | 93 | Thiobencarb | 93 |
| Simazine | 91 | Molinate | 91 |
| Butylate | 91 | Tebuthiuron | 91 |
| Dieldrin | 91 | Propargite | 91 |
| Propachlor | 90 | 2,6 Diethylanailin | 90 |
| EPTC | 90 | Prometon | 89 |
| Malathion | 89 | Alpha BCH | 88 |
| Ethoprop | 88 | Pebulate | 88 |
| Triallate | 87 | Propanil | 86 |
| Diazinon | 85 | Fonofox | 83 |
| Cyanazine | 83 | Lindane | 82 |
| Trifluralin | 81 | Pendimethalin | 81 |
| Ethalfluralin | 77 | Methyl-azinphos | 75 |
| Pronamide | 75 | Disulfoton | 74 |
| Benfluralin | 73 | Methyl-parathion | 72 |
| Phorate | 70 | P,P' DDE | 63 |
| Terbacil | 58 | Metribuzin | 57 |
| Permethrin | 52 | Deethylatrazine | 33 |
| **Pesticides (by HPLC)** | | | |
| Propham | 113 | Aldicarb sulfoxide | 99 |
| Linuron | 99 | Fenuron | 98 |
| 2,4,5-TP | 94 | Norflurazon | 90 |
| Carbofuran | 89 | Bentazon | 87 |
| Clopyralid | 87 | Oryzalin | 87 |
| Bromacil | 86 | 2,4,5-T | 86 |
| Dachthal (mono-acid) | 84 | Dichlorprop | 84 |
| 2,4-D | 82 | 3-OH-Carbofuran | 82 |
| Dinoseb | 77 | Fluometuron | 74 |
| Methomyl | 72 | Propoxur | 70 |
| Dichlobenil | 70 | Neburon | 65 |
| Picloram | 64 | MCPA | 63 |
| 4,6-DNOC | 58 | Bromoxynil | 53 |
| 2,4-DB | 52 | Diuron | 49 |
| Esfenvalerate | 45 | Triclopyr | 43 |
| Dicamba | 30 | | |

# RESULTS OF WATER-QUALITY ANALYSES

## Major Ions

The major ions analyzed in ground-water samples (table 8) are constituents common to almost all water samples. Major ions make up the bulk of dissolved constituents in natural water and generally are considered to be naturally occurring. However, the concentration of some major ions in ground water also may be affected by human activities. Naturally occurring contributions of major ions to ground water generally are the result of interactions between the water and the soil and aquifer material through which the water has passed. Examples of human activities that can affect major-ion concentrations are the application of road salt leading to larger salt concentrations in nearby ground water or evaporative concentration of major ions due to irrigation of lawns or crops. The minimum, median, and maximum concentrations for all major ions analyzed for the three South Platte River Basin water-quality studies are listed in table 12.

The relative percentages of major-ion concentrations (in terms of total milliequivalents per liter) in each whole water sample are shown in a trilinear diagram (Hem, 1989, p. 176) in figure 5. Trilinear diagrams are a convenient way to depict and compare water types for multiple samples. The water samples from the urban-crystalline study area generally plot in the Ca Mg $HCO_3$ part of the diagram, whereas the water samples from the agricultural-alluvium study area generally plot in the Ca Mg $SO_4$ Cl part. The water samples from the urban-alluvium study area tend to cluster somewhere in between. These individual clusters for the three study areas indicate different water types in each study area.

The total concentration of the combined major ions in a water sample can be indicated by the value of two general water-quality parameters—sum of dissolved solids (dissolved solids) and specific conductance. Dissolved solids is reported as a concentration value (in milligrams per liter) calculated by summing the measured concentrations for all major-ion species. Specific conductance is an indirect measurement of total dissolved ions in solution determined from the electrical conductivity of the water sample. The units for the measure of specific conductance are microsiemens per centimeter at 25 degrees Celsius (μS/cm). Dissolved-solids and specific-conductance measurements also are presented in table 12.

The distribution of dissolved-solids concentrations for the three study areas is shown in figure 6. Also shown for comparison in figure 6 is the EPA's secondary maximum contaminant level (SMCL) of 500 mg/L for dissolved solids in drinking water (U.S. Environmental Protection Agency, 1996b).

Dissolved-solids concentrations in the urban-crystalline study area generally were small (median = 203 mg/L), and median concentrations of sulfate ($SO_4$), chloride (Cl), and fluoride (F) also were less than their respective SMCL's (table 12). Only 1 of 27 ground-water samples from the urban-crystalline study area (637 mg/L) exceeded the 500-mg/L SMCL for dissolved solids. A median alkalinity of 116 mg/L [as calcium carbonate ($CaCO_3$)] for samples from the urban-crystalline study area indicates that the water in this aquifer is moderately hard (61–120 mg/L) (Hem, 1989, p. 159).

Median dissolved-solids concentrations in the urban-alluvium (833 mg/L) and the agricultural-alluvium (1,510 mg/L) study areas were greater than the 500 mg/L SMCL. Of the individual ions listed in the SMCL, the only median major-ion concentration to exceed the EPA limit was sulfate in the agricultural-alluvium study area (median = 695 mg/L, SMCL = 250 mg/L). Ion concentrations that exceeded the SMCL were measured in all three study areas as indicated by the maximum concentrations listed in table 12. Alkalinity levels in water samples from the urban-alluvium (median = 285.5 mg/L as $CaCO_3$) and the agricultural-alluvium (median = 302.5 mg/L as $CaCO_3$) study areas indicated that the water in this aquifer was very-hard ($CaCO_3$ >180 mg/L) (Hem, 1989, p. 159).

## Nutrients

Nutrients are compounds of nitrogen and phosphorus used by a variety of biota during metabolism. The chemical behavior of nutrient species in ground water is affected by the following: (1) Use by biota during metabolism; (2) the oxidation/reduction state of the ground-water environment; and (3) relatively low solubilities of inorganic compounds of phosphorus. Nitrate ($NO_3$) is the nutrient compound of main concern from a human health perspective, relative to

**Table 12.** Minimum, median, and maximum concentrations of major ions and selected water properties in well water from three study areas in the South Platte River Basin, 1993–95

[mg/L; milligrams per liter; µS/cm, microsiemens per centimeter at 25 degrees Celsius; µg/L, micrograms per liter; >, greater than; < less than; EPA SMCL's, U.S. Environmental Protection Agency (1996b) secondary maximum contaminant levels; --, no standard]

| Property or constituent | Urban-crystalline study area | | | Urban-alluvium study area | | | Agricultural-alluvium study area | | | EPA SMCL's |
|---|---|---|---|---|---|---|---|---|---|---|
| | Minimum (mg/L) | Median (mg/L) | Maximum (mg/L) | Minimum (mg/L) | Median (mg/L) | Maximum (mg/L) | Minimum (mg/L) | Median (mg/L) | Maximum (mg/L) | |
| Specific conductance (in µS/cm) | 32 | 330 | 1,340 | 627 | 1,290 | 4,290 | 819 | 2,145 | 4,270 | -- |
| pH-laboratory | 6.8 | 7.2 | 8.3 | 6.6 | 7.05 | 8.4 | 6.7 | 7.2 | 7.5 | 6.5–8.5 |
| Hardness | 11 | 140 | 490 | 220 | 415 | 890 | 290 | 795 | 1,700 | -- |
| Sum of dissolved solids | 21 | 203 | 637 | 377 | 833 | 2,330 | 552 | 1,510 | 3,470 | 500 |
| Alkalinity | 13 | 116 | 264 | 94 | 285.5 | 845 | 182 | 302.5 | 487 | -- |
| Calcium | 2.8 | 35 | 150 | 58 | 125 | 270 | 84 | 200 | 450 | -- |
| Magnesium | 0.99 | 9.4 | 38 | 11 | 24.5 | 59 | 19 | 67 | 160 | -- |
| Sodium | 1.2 | 11 | 57 | 34 | 120 | 500 | 50 | 170 | 480 | -- |
| Potassium | 0.4 | 1.6 | 4.4 | <0.1 | 5.05 | 48 | 4.4 | 14.5 | 59 | -- |
| Sulfate | 1.5 | 12 | 200 | 13 | 125 | 700 | 170 | 695 | 1,900 | 250 |
| Chloride | 0.2 | 8.2 | 330 | 30 | 87 | 1,200 | 20 | 92 | 210 | 250 |
| Fluoride | <0.1 | 0.6 | 3.1 | 0.4 | 0.9 | 4.1 | 0.2 | 1.15 | 2.6 | 2.0 |
| Bromide | <0.01 | 0.05 | 0.15 | 0.09 | 0.3 | 1.7 | 0.13 | 0.64 | 1.1 | -- |
| Silica | 6.1 | 18 | 30 | 8.3 | 19.5 | 33 | 18 | 30.5 | 61 | -- |
| Iron (in µg/L) | <3.0 | 5 | 600 | <3.0 | 8 | 31,000 | <3.0 | <3.0 | 13 | 300 |
| Manganese (in µg/L) | <1.0 | 3 | 112 | <1.0 | 1,59.5 | 11,000 | <1.0 | <1.0 | >1,000 | 50 |

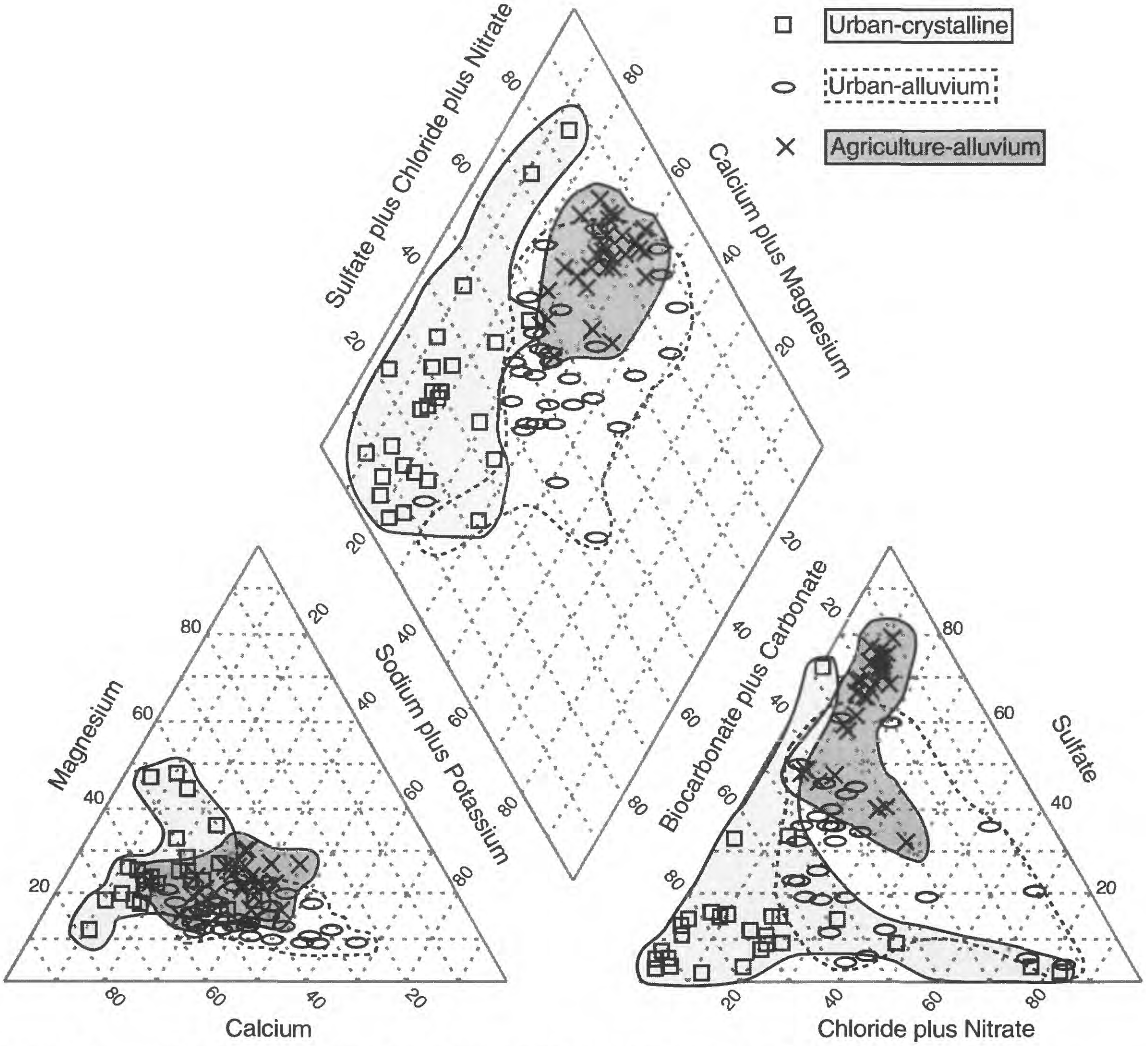
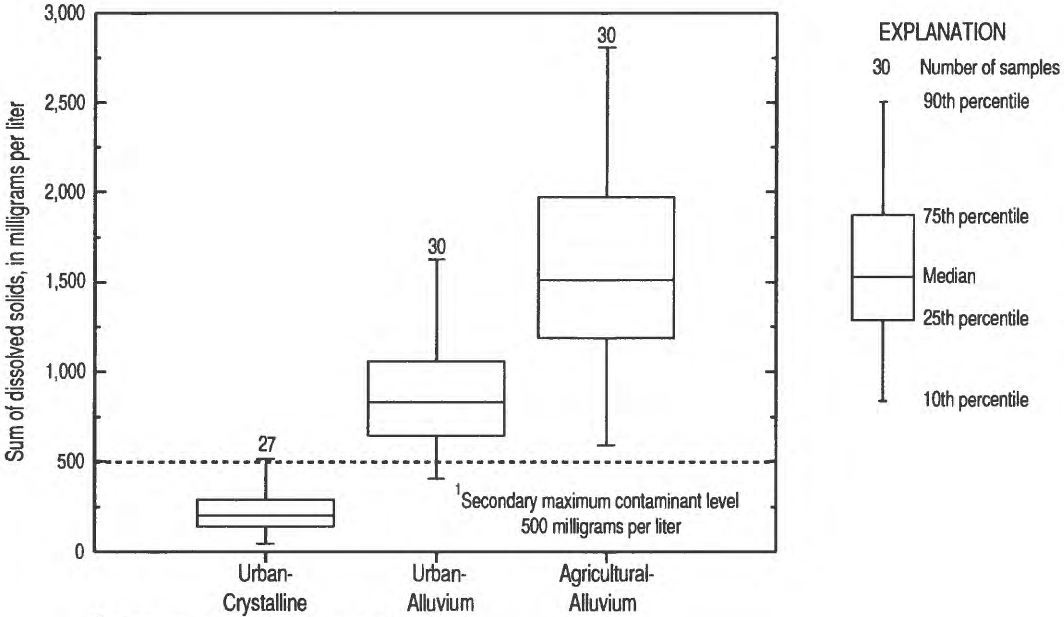


**Figure 5.** Trilinear diagram showing water types for three study areas in the South Platte River Basin, 1993–95 [nondetections set to 0.0 mg/L].

drinking water. Elevated nitrate concentrations in drinking water have been associated with increased rates of stomach cancer and methemoglobinemia, better known as blue baby syndrome (U.S. Environmental Protection Agency, 1994). The EPA has set a drinking-water maximum contaminant level (MCL) for nitrate ($NO_3$) and nitrite plus nitrate ($NO_2 + NO_3$) of 10 mg/L as nitrogen (U.S. Environmental Protection Agency, 1996b.)

The minimum, median, and maximum concentrations for all nutrient species analyzed in the three study areas are listed in table 13. The median concentrations of nutrient species generally were small with the exception of nitrite plus nitrate ($NO_2 + NO_3$) in the agricultural-alluvium study area (9.35 mg/L as nitrogen), which is only slightly less than the MCL of 10 mg/L as nitrogen. Nitrite-plus-nitrate concentrations exceeded the MCL in some wells in each of the three study areas. Only one sample from the urban-crystalline study area exceeded the $NO_2 + NO_3$ MCL with a concentration of 13 mg/L. In the urban-alluvium study area, four samples equaled or exceeded the MCL. In the agricultural-alluvium study area, 14 of 30 samples had $NO_2 + NO_3$ concentrations that equaled or exceeded the MCL. The distribution of $NO_2 + NO_3$ concentrations for each of the three study areas is shown in figure 7*A*.

The distribution of dissolved ammonium concentrations measured in each study area is shown in figure 7*B*. Isolated large concentrations of ammonium were measured in some ground-water samples from the urban-alluvium study area. Ammonium is a reduced form of nitrogen and generally is associated with ground water having low dissolved-oxygen concentrations. Field measurements indicated that



[1]U.S Environmental Protection Agency, 1996b

**Figure 6.** Box plots showing distribution of dissolved-solids concentrations in well water from three study areas in the South Platte River Basin, 1993–95.

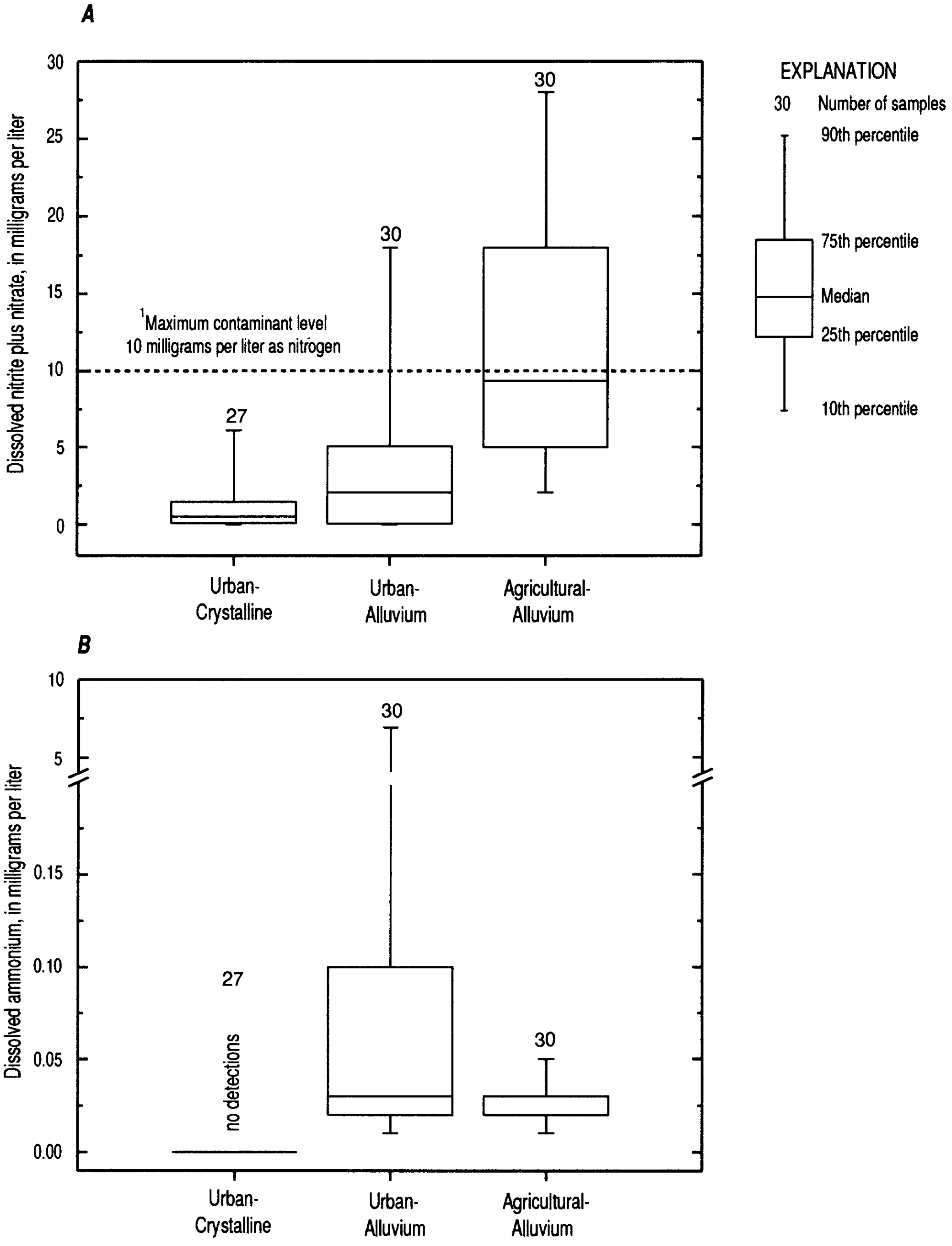
anaerobic conditions (dissolved oxygen <1.0 mg/L) existed in the aquifer at well sites with larger ammonium concentrations. In oxygenated ground water, ammonium usually is quickly converted to nitrate.

Concentrations of dissolved phosphorus and orthophosphate were small in the ground water of all three study areas (table 13). Small phosphorus concentrations in ground-water samples generally are the result of the low solubility of most inorganic phosphorus compounds and their use by biota as nutrients (Hem, 1989, p. 126).

**Table 13.** Minimum, median, and maximum concentrations for nutrient species analyzed in well water for three study areas in the South Platte River Basin, 1993–95

[mg/L, milligrams per liter; <, less than; EPA, U.S. Environmental Protection Agency; MCL's, maximum contaminant levels; HA's, health advisories; --, no standard]

| Nutrient | Urban-crystalline study area | | | Urban-alluvium study area | | | Agricultural-alluvium study area | | | EPA MCL's | EPA HA's |
|---|---|---|---|---|---|---|---|---|---|---|---|
| | Minimum (mg/L) | Median (mg/L) | Maximum (mg/L) | Minimum (mg/L) | Median (mg/L) | Maximum (mg/L) | Minimum (mg/L) | Median (mg/L) | Maximum (mg/L) | | |
| Nitrite | <0.01 | <0.01 | <0.01 | <0.01 | <0.01 | 0.02 | <0.01 | <0.01 | 0.12 | 1 | -- |
| Nitrite plus nitrate | <0.05 | 0.55 | 13 | <0.05 | 2.1 | 24 | 0.15 | 9.35 | 52 | 10 | -- |
| Ammonium as nitrogen | <0.015 | <0.015 | 0.04 | <0.015 | 0.03 | 23 | <0.015 | 0.02 | 1.2 | -- | 30 |
| Ammonium plus organic nitrogen | <0.2 | <0.2 | <0.2 | <0.2 | <0.2 | 29 | <0.2 | 0.4 | 1.6 | -- | -- |
| Phosphorus | <0.01 | <0.01 | 0.06 | <0.01 | 0.02 | 7 | <0.01 | 0.04 | 0.24 | -- | -- |
| Orthophosphate as phosphorus | <0.01 | <0.01 | 0.04 | <0.01 | 0.02 | 4.3 | <0.01 | 0.04 | 0.22 | -- | -- |



[1]U.S Environmental Protection Agency, 1996b

**Figure 7.** Box plots showing distribution of (*A*) dissolved-nitrite-plus-nitrate concentrations, and (*B*) dissolved-ammonium concentrations for three study areas in the South Platte River Basin, 1993–95 [nondetections set to 0.0 mg/L].

## Volatile Organic Compounds

The constituent class, volatile organic compounds (VOC's), includes organic solvents, chlorinated disinfectants, and many petroleum-based products including components of gasoline, fuel oils, and oil-based lubricants. Other VOC's are degradation or naturally derived byproducts of these compounds. The 59 VOC's analyzed in each water sample from the three South Platte River Basin study areas are listed in table 8. Because most VOC's listed in table 8 are synthetic, the occurrence of these compounds in ground water is direct evidence of human effects on water quality.

VOC's were detected in the urban-crystalline and urban-alluvium study areas. There were no VOC detections in the agricultural-alluvium study area. All VOC's detected in the two urban study areas, the percentage of well samples containing each compound, and the maximum concentrations measured are shown in figure 8. In the urban-crystalline study area, 8 different VOC's were detected in 8 of 27 wells sampled. Three of these eight wells had more than one VOC detected. No water sample in the urban-crystalline study area had VOC concentrations that exceeded an MCL. In the urban-alluvium study area, 31 of 59 analyzed VOC's were detected at least once, and 25 of 29 sampled wells had at least one VOC detected. The urban-alluvium study area had much higher total VOC concentrations than those measured in the urban-crystalline study area (fig. 9). Three compounds in the ground water of the urban-alluvium study area—benzene, tetrachloroethylene, and methyl-tert-butyl-ether—exceeded, at least once, the MCL or lifetime exposure health advisory (HA) for that compound.

Methyl-tert-butyl-ether (MTBE), a gasoline additive, and chloroform were the most frequently detected VOC's in the urban-crystalline study area (3 of 27 wells sampled) (fig 8). Trihalomethane compounds, of which chloroform is one, was the most frequently detected group of VOC's in this study area. Trihalomethane compounds in ground water may be the result of chlorine disinfection of drinking water. The highest chloroform concentration (74.0 µg/L) for all three study areas was measured in a well in the urban-crystalline study area that had been installed just prior to sampling. Chloroform and other trihalomethane compounds also were detected in the ground water of the urban-alluvium study area, generally at lower concentrations than measured in the urban-crystalline study area. The EPA's 1994 proposed rule for disinfectants and disinfection byproducts, such as chloroform, in drinking water recommends that total concentrations for all trihalomethanes combined not exceed 80 µg/L (U.S. Environmental Protection Agency, 1996b.)

MTBE was the most frequently detected VOC in the urban-alluvium study area, being detected in 23 of 29 (79 percent) wells sampled. MTBE is apparently widespread in the alluvial ground water of the Denver metropolitan area. Other petroleum products and chlorinated solvents, or their breakdown products, comprised most of the remaining VOC's detected in the urban-alluvium study area. Chlorinated solvents, such as tetrachloroethylene and trichloroethane, were detected in the urban-crystalline and urban-alluvium study areas.

## Pesticides

The pesticide compounds analyzed in ground-water samples from the three study areas and the analytical MRL's for each compound are listed in table 8. The list includes 76 herbicides, insecticides, and pesticide degradation products. Pesticide compounds were present in the ground water of the urban-alluvium and agricultural-alluvium study areas; however, there were no detections of pesticides in wells from the urban-crystalline study area. All pesticide compounds that were detected in the two alluvium study areas are listed in table 14. Also listed are the number of detections for each compound per number of wells sampled and the maximum concentrations detected for each compound compared to the MCL's or HA's.

Although concentrations were small, pesticides were widely distributed in the ground water of the two alluvium study areas. In the urban-alluvium study area, 27 of 30 wells sampled (90 percent) had detectable concentrations of at least one pesticide or breakdown product. In the agricultural-alluvium study area, 29 of 30 wells sampled (about 97 percent) had detectable concentrations of at least one pesticide or breakdown product. Herbicides (14 compounds) were detected more frequently in the two alluvium study areas than insecticides (3 compounds).

The distribution of the sum of all pesticide concentrations for each well by study area is shown in figure 10. Although pesticide compounds were present

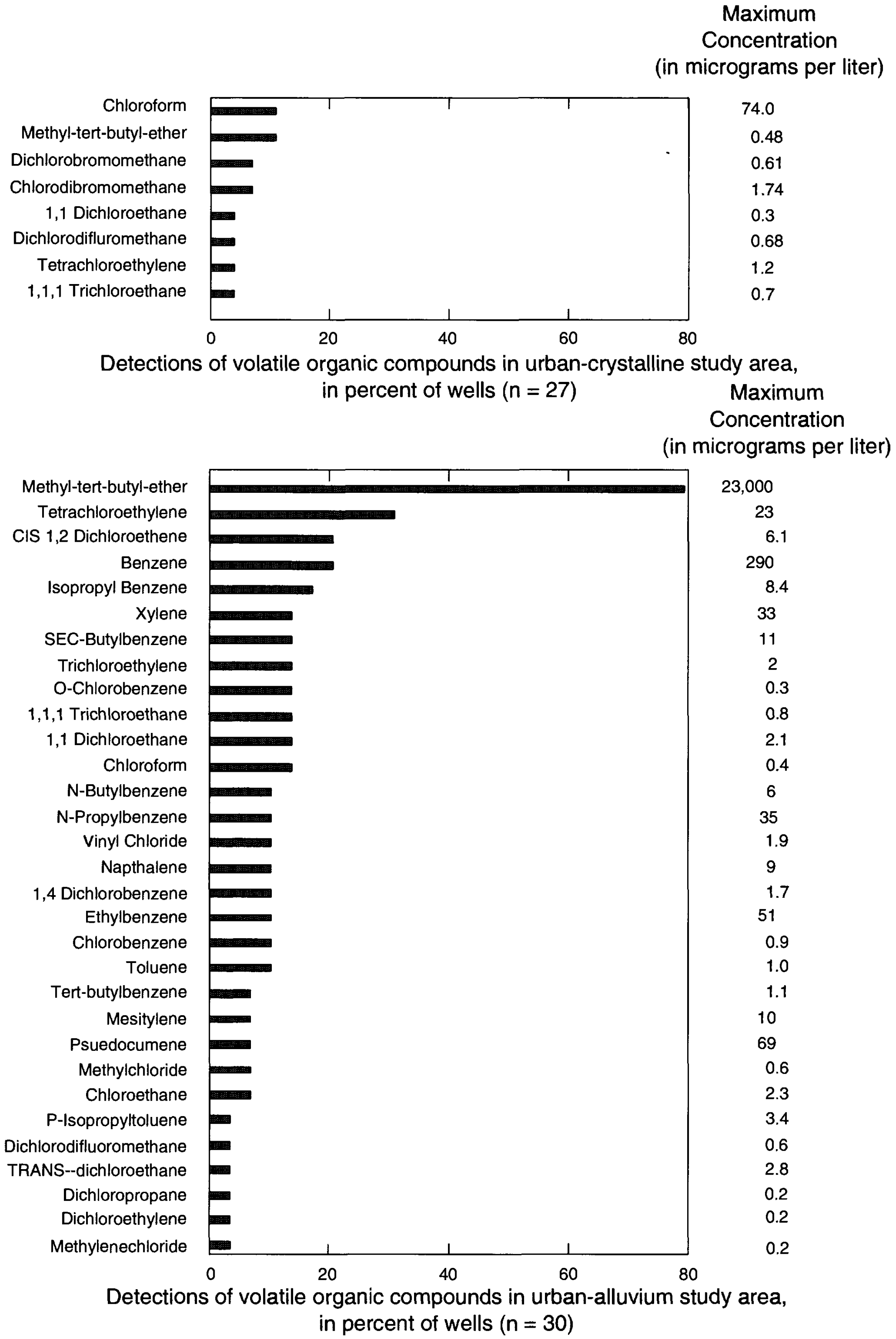


**Figure 8.** Percentage of well samples containing detected volatile organic compounds and maximum concentrations in urban-crystalline and urban-alluvium study areas of the South Platte River Basin, 1993–95.

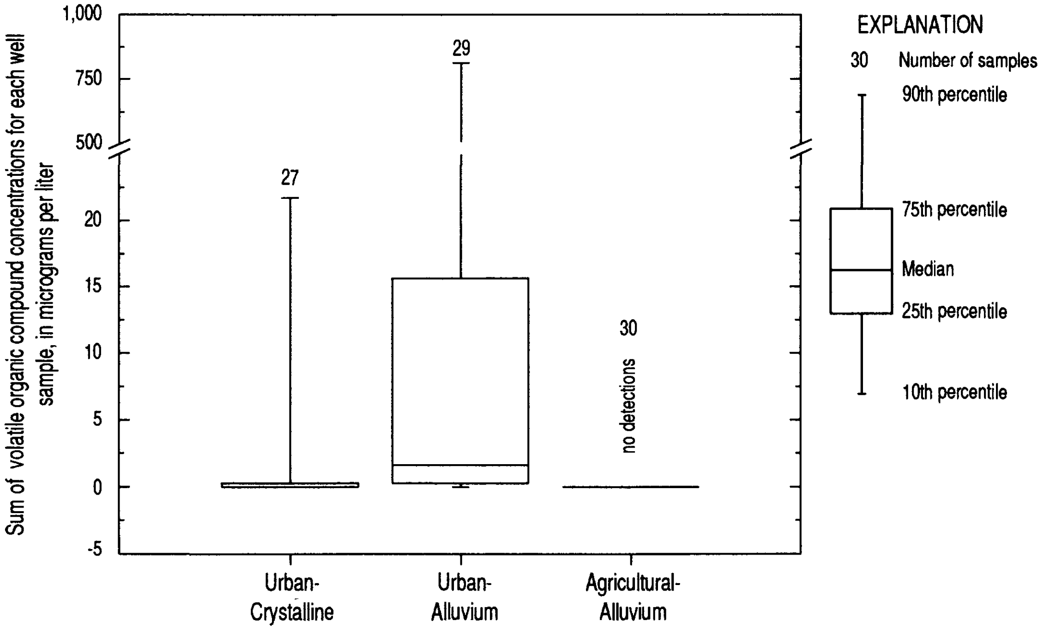


**Figure 9.** Box plots showing distribution of summed volatile organic compound concentrations in three study areas in the South Platte River Basin, 1993–95.

in a large number of sampled wells in the urban-alluvium and agricultural-alluvium study areas, the sum of pesticide concentrations in wells from the agricultural-alluvium study area generally was larger than the sum of pesticide concentrations measured in ground water from the urban-alluvium study area. There are no EPA guidelines for exposure to multiple pesticide compounds in drinking water.

Seven pesticide compounds were common to ground-water samples collected from the urban-alluvium and agricultural-alluvium study areas. In these study areas, the compounds atrazine, deethylatrazine, prometon, and simazine were four of the top five most frequently detected pesticide compounds. Maximum concentrations for the detected pesticide compounds in both study areas were less than the MCL's and HA's for drinking water.

## Trace Elements and Radon

Trace elements generally are naturally occurring metals and other inorganic constituents that have a low abundance in the crustal rocks at the Earth's surface. The low abundance and poor solubility in water of most of these elements generally result in trace concentrations (<1.0 mg/L) in natural water samples. Concentrations of some of these elements may reach several milligrams per liter in ground water affected by industrial wastes. The trace elements analyzed in water samples collected from the three South Platte River Basin study areas and the minimum, median, and maximum concentrations measured are listed in table 15. Although not considered a trace element, radon is included in this discussion and in table 15 because radon-222 is a product of the radioactive decay of uranium-238. Also listed in table 15 are the drinking-water MCL's and SMCL's for these constituents.

Some constituents exceeded the proposed or finalized drinking-water standards in each of the three study areas. The concentrations of manganese and uranium were relatively large compared to proposed or finalized drinking-water standards. The box plots that represent the distribution of concentrations for these elements (and arsenic, cobalt, selenium, and radon) in the three study areas are shown in figure 11*A*–11*F*. For information on the primary health

**Table 14.** Pesticide compounds detected in the alluvium study areas in the South Platte River Basin, 1993–95

[µg/L, micrograms per liter; --, no standard]

| Pesticide compound | Pesticide type | Number of detections/ number of wells | Maximum concentration (µg/L) | Maximum contaminant level[1] (µg/L) | Health advisory, lifetime[1] (µg/L) | Primary use |
|---|---|---|---|---|---|---|
| **Urban-alluvium study: 27 of 30 wells had detectable pesticides** | | | | | | |
| Prometon | Herbicide | 24/30 | 1.4 | -- | 100 | Nonselective soil sterilant. |
| Atrazine | Herbicide | 7/30 | .21 | 3.0 | -- | Pre- and early post-emergent weed control in corn. |
| Simazine | Herbicide | 7/30 | .068 | 4.0 | -- | Nonselective soil sterilant. |
| Tebuthiuron | Herbicide | 5/30 | .079 | -- | 500 | Surface applied control of woody plants and vines. |
| Deethylatrazine | Breakdown product | 2/30 | .19 | -- | -- | Breakdown product of atrazine |
| Dieldrin | Insecticide | 2/30 | .045 | -- | -- | Control of soil insects in selected crops. |
| 2,4-D | Herbicide | 1/30 | .17 | 70.0 | -- | Broadleaf control in cereal crops, pastures, and lawns. |
| Bromacil | Herbicide | 1/30 | 1.2 | -- | 90 | General weed, brush control in noncrop areas. |
| Metribuzin | Herbicide | 1/30 | .043 | -- | 200 | Pre- and post-emergent weed control in potatoes. |
| **Agricultural-alluvium study: 29 of 30 wells had detectable pesticides** | | | | | | |
| Deethylatrazine | Breakdown product | 29/30 | 0.84 | -- | -- | Breakdown product of atrazine |
| Atrazine | Herbicide | 28/30 | 1.6 | 3.0 | -- | Pre- and early post-emergent weed control in corn. |
| Prometon | Herbicide | 23/30 | 40.0 | -- | 100.0 | Nonselective soil sterilant. |
| Metolachlor | Herbicide | 6/30 | 2.7 | -- | 70.0 | Pre-emergent weed control in corn. |
| Simazine | Herbicide | 5/30 | .05 | 4.0 | -- | Nonselective soil sterilant. |
| Tebuthiuron | Herbicide | 3/30 | .045 | -- | 500.0 | Surface applied control of woody plants and vines. |
| Carbofuran | Insecticide | 2/30 | .17 | 40.0 | -- | Broad spectrum insect control in corn, alfalfa, and potatoes. |
| EPTC | Herbicide | 2/30 | .45 | -- | -- | Pre-plant incorporate for weed control in several crops. |
| Alachlor | Herbicide | 1/30 | .12 | 2.0 | -- | Pre-emergent weed control in corn and other agronomic crops. |
| Bentazon | Herbicide | 1/30 | .07 | -- | 20.0 | Post-emergent broadleaf control in corn, drybeans, and soybeans. |
| Bromacil | Herbicide | 1/30 | 4.9 | -- | 90.0 | General weed, brush control in noncrop areas. |
| DCPA | Herbicide | 1/30 | 10.0 | -- | 4,000 | Pre-emergent weed control in onions. |
| Diazinon | Insecticide | 1/30 | .047 | -- | .6 | Control of many soil and household insects. |
| Dieldrin | Herbicide | 1/30 | .014 | -- | -- | Control of soil insects in selected crops. |
| Diuron | Herbicide | 1/30 | .08 | 10.0 | -- | Soil sterilant or selective control of broadleaf grasses and weeds. |

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[1] U.S. Environmental Protection Agency, 1996b.

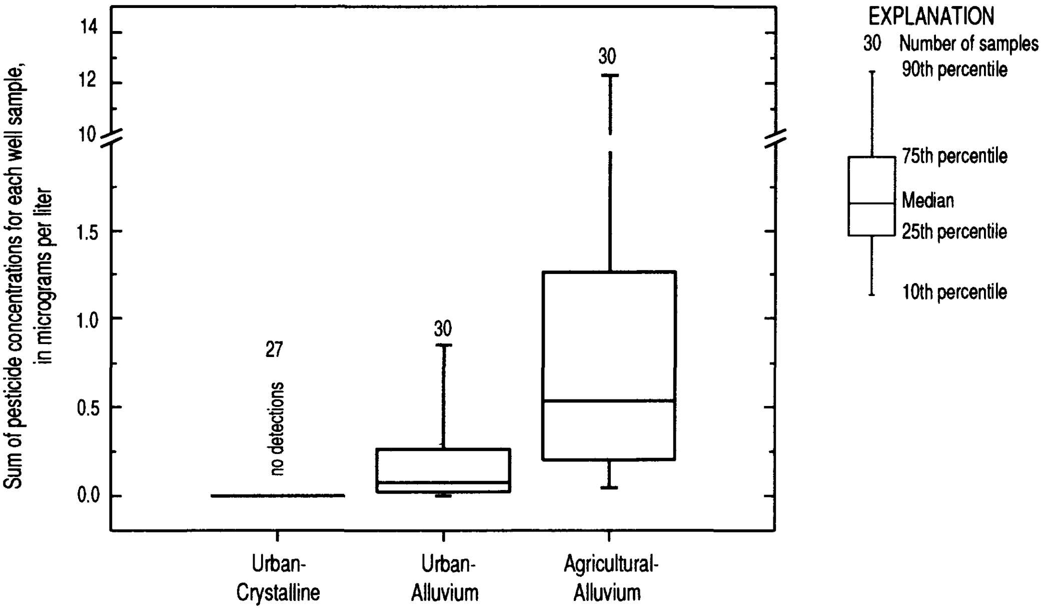


**Figure 10.** Box plots showing distribution of summed pesticide concentrations in three study areas in the South Platte River Basin, 1993–95.

effects related to these compounds, see Moore (1991), van der Leeden and others (1991), U.S. Environmental Protection Agency (1994).

Concentrations of manganese (fig. 11*A*) exceeded the 50-µg/L SMCL in some samples from each of the three study areas and occasionally were larger than could be quantified by the laboratory analytical technique (table 15). The largest concentrations were in the two alluvium study areas. Iron and manganese oxide coatings are known to be common in these sediments (see "Alluvial Aquifer" section). In the urban-alluvium study area, 18 of 30 samples exceeded the 50-µg/L SMCL for manganese; 11 of these 18 samples had manganese concentrations that were greater than 1,000 µg/L.

Cobalt (fig. 11*B*) is mentioned briefly here because it was detected only in water samples from the urban-alluvium study area. Hem (1989, p. 138) discussed the close association of cobalt with oxides of manganese and iron. A theoretical model coupling cobalt oxidation to a two-step manganese oxidation process is suggested to predict the concentration of cobalt in aqueous systems in which manganese oxide precipitates are present (Hem, 1978). In the urban-alluvium study area, water samples from wells that contained dissolved cobalt generally contained the larger manganese concentrations.

Arsenic (fig. 11*C*) concentrations increased from the urban-crystalline study area in the mountainous western part of the basin to the agricultural-alluvium study area in the eastern plains. Increasing concentrations from west to east (downstream) in the South Platte River Basin also were observed for selenium (fig. 11*D*) and uranium (fig. 11*E*), suggesting that the occurrence of these three trace elements may be related. The 33-µg/L concentration for arsenic in one sample from the urban-alluvium study area (table 15) approaches the 50-µg/L MCL. The 33-µg/L concentration in this sample is greater than any other arsenic concentration measured in the three study areas and may have been derived from an industrial source.

Selenium (fig. 11*D*), an element essential in the nutrition of grazing animals, has been shown to have toxic effects at high concentrations. The MCL of 50 µg/L was exceeded in only one sample collected from a well in the urban-alluvium study area (66 µg/L) (table 15). A recognized source of selenium in the Western United States is the shale rock units of Cretaceous age, including the Pierre Shale in the South Platte River Basin (Severson and others, 1991). Howard (1977) associates selenium geochemistry with that of uranium and indicates that some uranium ore deposits in sandstones of the Western United States are sources of selenium. Selenium occurrence also has

**Table 15.** Minimum, median, and maximum concentrations of trace elements and radionuclides in well water from three study areas in the South Platte River Basin, 1993–95

[µg/L, micrograms per liter; pCi/L, picocuries per liter; <, less than; >, greater than; --, no standard; EPA, U.S. Environmental Protection Agency; MCL, maximum contaminant level; SMCL, secondary maximum contaminant level]

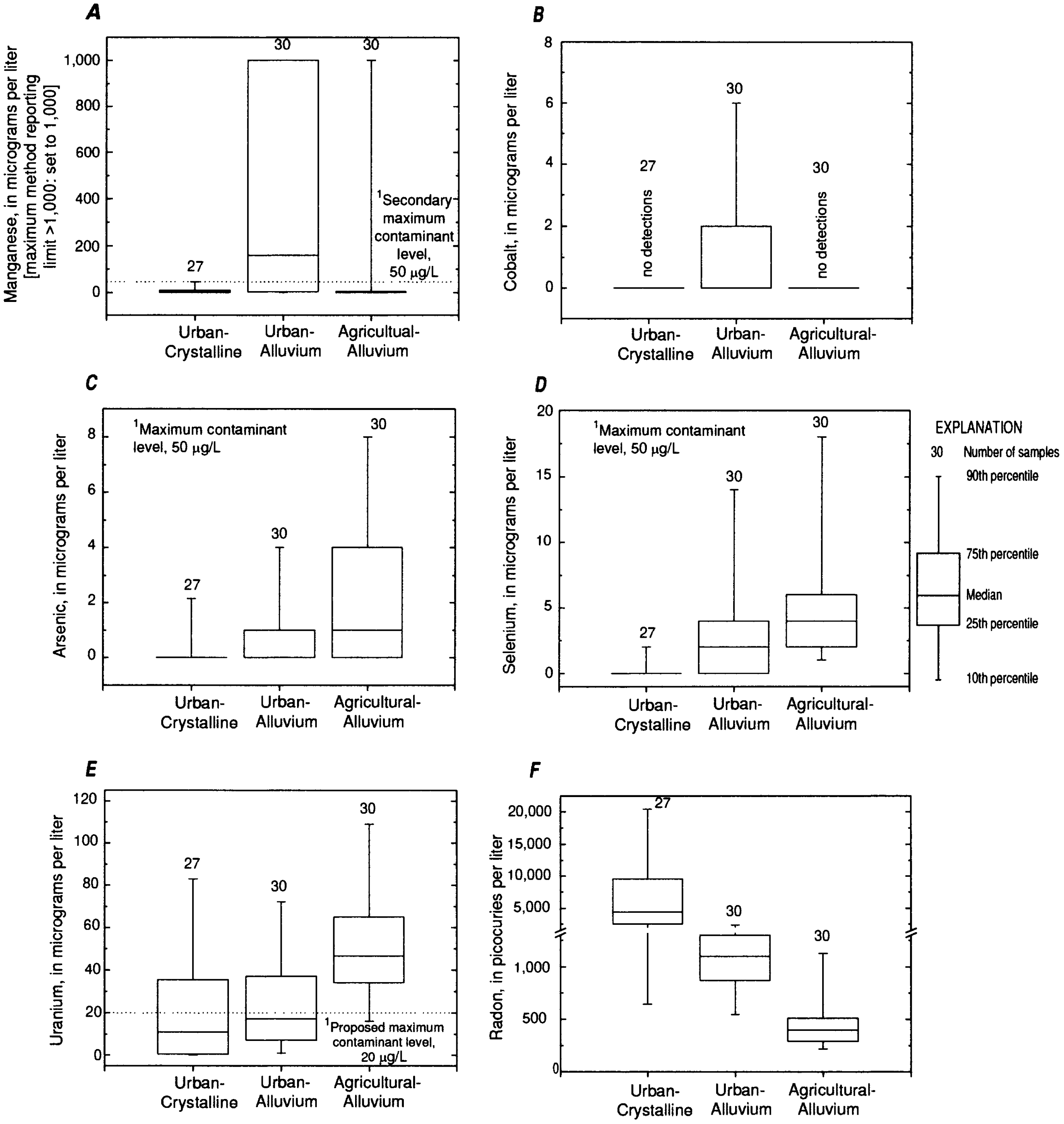
| Trace element or radionuclide | Urban-crystalline study area | | | Urban-alluvium study area | | | Agricultural-alluvium study area | | | EPA, MCL or SMCL[1] |
|---|---|---|---|---|---|---|---|---|---|---|
| | Minimum | Median | Maximum | Minimum | Median | Maximum | Minimum | Median | Maximum | |
| | | | | **Trace element, in micrograms per liter** | | | | | | |
| Aluminum | 3 | 4 | 56 | <1.0 | 4 | 8 | 2 | 5 | 13 | 50–200 (SMCL) |
| Antimony | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | 6.0 (MCL) |
| Arsenic | <1.0 | <1.0 | 3 | <1.0 | <1.0 | 33 | <1.0 | 1 | 8 | 50 (MCL) |
| Barium | 3 | 49 | 322 | 18 | 109 | 577 | 17 | 35.5 | 112 | 2,000 (MCL) |
| Beryllium | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | 4 (MCL) |
| Cadmium | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | 5 (MCL) |
| Chromium | <1.0 | 2 | 6 | <1.0 | <1.0 | 3 | <1.0 | 5 | 8 | 100 (MCL) |
| Cobalt | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | 9 | <1.0 | <1.0 | <1.0 | -- |
| Copper | <1.0 | 11 | 156 | <1.0 | 2 | 14 | <1.0 | 3 | 15 | 1,300 (action level) |
| Lead | <1.0 | <1.0 | 3 | <1.0 | <1.0 | 3 | <1.0 | <1.0 | <1.0 | 15 (action level) |
| Manganese | <1.0 | 3 | 112 | <1.0 | 160 | >2,000 | <1.0 | <1.0 | >1,000 | 50 (SMCL) |
| Molybdenum | <1.0 | 2 | 34 | <1.0 | 3 | 11 | <1.0 | 3 | 38 | Listed for regulation |
| Nickel | <1.0 | 2 | 7 | 1 | 3 | 20 | <1.0 | 3 | 33 | 100 (MCL) |
| Selenium | <1.0 | <1.0 | 2 | <1.0 | 2 | 66 | 1 | 4 | 24 | 50 (SMCL) |
| Silver | <1.0 | <1.0 | 1 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | <1.0 | 100 (SMCL) |
| | | | | **Radionuclides** | | | | | | |
| Radon (in pCi/L) | 41 | 4,400 | 23,000 | 230 | 1,100 | 2,600 | 170 | 400 | 1,600 | -- |
| Uranium (in µg/L) | <1.0 | 11 | 156 | <1.0 | 17 | 80 | 9 | 46.5 | 146 | 20 (proposed MCL) |

[1] U.S. Environmental Protection Agency, 1996b.

been correlated with the presence of oxides of iron and manganese (Balistrieri and Chao, 1990). All of these are potential sources in the South Platte River Basin.

Uranium appears to be ubiquitous in the shallow ground water of the South Platte River Basin. Uranium concentrations in 49 of 87 wells sampled exceeded the proposed 20-µg/L drinking-water standard, indicating that background concentrations of uranium are large in the South Platte River Basin. The distribution of uranium concentrations in each study area relative to the proposed drinking-water standard is shown in figure 11*E*. Concentrations of uranium equaled or exceeded the proposed MCL in 10 of 27 wells (about 37 percent) in the urban-crystalline study area, 12 of 30 wells (40 percent) in the urban-alluvium study area, and 27 of 30 wells (90 percent) in the agricultural-alluvium study area. The single highest uranium concentration (156 µg/L) (table 15) was measured in a water sample collected from the urban-crystalline study area; however, several samples from the agricultural-alluvium study area had similar concentrations. The median concentration from the agricultural-alluvium study area (46.5 µg/L) was much higher than median concentrations for the other two study areas (table 15).

Radon gas ($^{222}$Rn) is a product of the radioactive decay of uranium. Radon concentrations greater than 1,000,000 pCi/L have been measured in ground water in several parts of the United States; the national average is 350 pCi/L (Paulsen, 1991). The minimum, median, and maximum concentrations measured in the three South Platte River Basin study areas are listed in table 15. Similar to uranium, the background concentrations of radon in the South Platte River Basin also are large, with the median concentrations from each of the three study areas exceeding the national average. Although radon is produced during the radioactive decay of uranium, the box plots of these two



[1]U.S Environmental Protection Agency, 1996b

**Figure 11.** Box plots showing distribution of concentrations for selected trace elements and radon in three study areas in the South Platte River Basin, 1993–95 [nondetections set to 0.0 µg/L].

constituents for the three study areas (fig. 11*E* and 11*F*) show apparent opposite relations. This apparent inverse relation is not statistically significant when evaluated with linear regression on paired uranium/radon concentrations ($R^2 = 0.02$; $p = 0.19$).

Should the proposed drinking-water standard for uranium be finalized at the current 20-µg/L concentration or the drinking-water standard for radon be set at a low concentration, the future use of shallow ground water in the South Platte River Basin as a drinking-water resource might be affected.

### Tritium

Tritium is a heavy isotope of hydrogen. Tritium atoms are unstable and undergo radioactive decay with a half life of about 12.3 years. Consequently, the presence of tritium in ground water has been used as an age-dating tool to estimate the time that the water entered the aquifer and became isolated from the atmospheric source of tritium. During the 1950's and early 1960's, a substantial amount of anthropogenic tritium was released to the Earth's atmosphere during above-ground nuclear testing of hydrogen bombs. This atmospheric spike of tritium can be observed in ground water recharged during and after this time. Tritium concentrations in precipitation have varied considerably from place to place during different years and seasons, making the use of tritium as a short-term dating tool problematic. Tritium can, however, be used as a semiquantitative dating tool in the following way: (1) Ground water having little or no tritium [less than 1.5 pCi/L or 0.5 tritium units (T.U.)] generally is considered to have been recharged to the aquifer prior to 1952 (pre-bomb water); (2) ground water with large tritium concentrations (greater than 30 pCi/L or 10 T.U.) is thought to have been recharged after 1952 (post-bomb water); and (3) ground water with tritium concentrations between these levels is considered a mixture of pre- and post-bomb water. However, it is impossible to determine the percentage of water contributed by each period on the basis of tritium data alone (Mazor, 1991). Tritium age dating of ground water in the South Platte River Basin study areas indicates the significance of nondetections of synthetic compounds. If a water sample does not contain synthetic constituents, it is important to document that these nondetections are not simply the result of sampling water that is older than 1952.

Tritium samples were collected only in the urban-crystalline and agricultural-alluvium study areas. Tritium was not collected in the urban-alluvium study area because prior knowledge of the hydrodynamics in the urban alluvium suggested short ground-water flow-through times (Robson, 1989). This assumption eventually was supported by the widespread occurrence of synthetic compounds in the urban-alluvium study area, particularly the VOC MTBE (in 79 percent of wells) whose use in the urban-alluvium study area did not begin until at least the mid-1970's.

Tritium concentrations in water samples from the agricultural-alluvium study area indicate that all well waters were recharged after 1952. The minimum (31.4 pCi/L), median (102.5 pCi/L), and maximum (180 pCi/L) tritium concentrations in the 30 wells in the agricultural-alluvium study area were all in the range that indicates recent recharge or modern water.

Six samples in the urban-crystalline study area had low concentrations of tritium (<30 pCi/L). These six samples were clustered in three separate areas (fig. 2)—southwest of Evergreen, Colo. (well 4 = 22.4 and well 11 = 25.9 pCi/L); near Rollinsville, Colo. (well 18 = 1.6 and well 21 = 3.5 pCi/L); and two of three samples in the vicinity of Estes Park, Colo. (well 26 = <2.5 and well 24 = 12.2 pCi/L). The tritium concentrations in the Rollinsville and Estes Park areas are low enough to suggest that ground water in these wells might be of pre-bomb origin. Tritium concentrations in the area southwest of Evergreen were in the range indicating a possible mixture of pre- and post-bomb water.

## RELATION OF WATER QUALITY TO STUDY AREA SETTINGS

The three study areas discussed in this report—urban-crystalline, urban-alluvium, and agricultural-alluvium—focus on the land-use settings likely to have the greatest effect on ground-water quality and the primary water-table aquifers in the South Platte River Basin. Results from the three study areas provide information on the range of water-quality conditions and possible land-use effects associated with each setting. The nested design of these ground-water-quality studies—having urban settings over two different aquifers and two different land-use settings over basically the same alluvial aquifer—allow comparisons between study areas that more clearly identify water-quality characteristics associated with land use compared to those related to water/aquifer material interactions. The physical location of the three study areas allows evaluation of ground-water quality in a downstream order. The mountainous western part of the basin (urban-crystalline study area) is the primary recharge area for the basin, having much greater annual precipitation. Water then flows through the Front Range urban corridor at the transition from mountains to plains and downstream to the mouth of the basin on the eastern plains where water exits the South Platte River Basin. Water-quality differences determined in study areas arranged in this downstream order can be thought of as a continuum and reveal the evolution of water quality as the water flows through the basin. Although the three study areas are not necessarily connected hydrologically, most water in the basin eventually flows through each area and carries the cumulative water-quality effects. The downstream evolution of water quality helps determine how different land-use settings and the reuse of the limited resource affect ground-water quality.

The urban-crystalline study area needs to be qualified as an urban land-use setting under the suggested nested design. The crystalline bedrock aquifer is exposed over almost the entire mountainous South Platte River Basin, and the predominant land cover overlying the crystalline bedrock aquifer is forest. The amount of urban land cover overlying the crystalline bedrock aquifer is only about 3 percent of the area outlined in figure 2. Mountain urban land use in the urban-crystalline study area is different from the urban setting in the urban-alluvium study area in metropolitan Denver. Mountain urban settings occur in localized pockets and mainly are residential developments with little commercial or industrial land. Although all wells sampled in the urban-crystalline study area were located near areas designated as urban by Fegeas and others (1983), the complexity of ground-water flow paths in the fractured crystalline bedrock aquifer makes determining the location of ground-water recharge for a given well problematic. For the purposes of interpretation, water samples collected from wells in the urban-crystalline study area were assumed to be associated with the urban land-use setting near each well.

Throughout this report, the concentration of water-quality constituents are discussed relative to national drinking-water standards. Only those wells sampled in the urban-crystalline study area were being used as a drinking-water supply at the time of sampling. Although no wells sampled in the urban-alluvium nor agricultural-alluvium study areas were being used for drinking water, some wells in the alluvial aquifer were being used as public or domestic drinking-water supply wells at the time of sampling. Future demands for drinking-water supplies may force greater development of the highly productive alluvial aquifer for this purpose. An evaluation of the alluvial aquifer relative to drinking-water standards provides a meaningful assessment of the quality of the resource.

## Urban-Crystalline Study Area

The urban-crystalline study area in the mountainous western part of the South Platte River Basin was much less intensely developed than the urban-alluvium or agricultural-alluvium study areas. The urban-crystalline study area also is located in the primary recharge area for most of the water flowing through the basin. These factors equate to less intensive use of the water resources and the probability of fewer anthropogenic effects on water quality.

The location of the urban-crystalline study area near the upstream end of the continuum of water flow through the South Platte River Basin also helps indicate the chemical evolution of water quality in the basin. Each rock unit and human process that contacts the water as it flows through the basin contributes dissolved constituents to the system. The trilinear diagram (fig. 5) shows a clustering of water types for each of the three ground-water-quality study areas. The water-quality analyses from the urban-crystalline study area generally cluster at one end of the range of water types determined for the three study areas. The transition in water type from the urban-crystalline study area in the west, where the predominant anion is bicarbonate, to the agricultural-alluvium study area on the eastern plains, where the predominant anions are sulfate and chloride, indicates a downstream evolution in water quality. The progressive downstream increase in the concentration of dissolved solids for the three study areas (fig. 6) also suggests that the chemical evolution of ground-water quality in the South Platte River Basin begins near the urban-crystalline study area. The smaller concentrations of dissolved solids in the urban-crystalline study area are the result of aquifer materials that are resistant to dissolution by ground water and indicate the minimal overall effects of the small urbanized pockets in this study area.

Ground-water quality in the urban-crystalline study area is not completely invulnerable to anthropogenic effects. Most of the wells sampled were in areas where individual household septic-disposal systems were the only treatment choice for domestic wastewater. Septic leach fields can be a source of a variety of anthropogenic constituents to ground water, particularly nutrients. In the urban-crystalline study area, nitrate concentrations exceeded the MCL of 10 mg/L as nitrogen in only 1 of 27 wells sampled. However, nitrate concentrations measured in ground water that are larger than 2 mg/L as nitrogen generally are considered to be affected by an anthropogenic source of nitrogen (Mueller and Helsel, 1996, p. 15). Nitrate concentrations in 5 of 27 wells in the urban-crystalline study exceeded 2 mg/L. Nitrate does not appear to be a major ground-water-quality concern in the urban-crystalline study area at this time; however, some mountain communities are imposing restrictive septic-construction rules due to high nitrate concentrations in the ground water (Mindy Ramig, Jefferson County Health Department, oral commun., 1996). The degradation of ground-water quality from septic leach fields in the urban-crystalline study area appears to be site specific.

Other evidence of anthropogenic effects to ground-water quality in the urban-crystalline study area was the presence of VOC's in 8 of 27 wells sampled. The fact that chloromethane compounds were the most frequently detected group of VOC's in the urban-crystalline study area may be evidence of disinfection of individual domestic wells in the bedrock aquifer or the isolated application of chlorinated public-supply water for lawn irrigation. The presence of MTBE in ground water in the urban-crystalline study area indicates relatively recent urban effects on water quality. MTBE has only been heavily used in the South Platte River Basin since the mid-1980's. This presence of MTBE indicates that increasing population in the mountainous part of the South Platte River Basin might introduce other synthetic compounds to the crystalline bedrock aquifer.

The lack of pesticide detections in the urban-crystalline study area may be related directly to land-use practices in the mountains. There is minimal cultivation and irrigation, neither crops nor lawn, in the mountain communities, due mainly to the lack of irrigation water from low-productivity wells. Mountain home owners tend to choose natural landscaping techniques and native vegetation. These land-use practices generally do not require pesticide application.

Another possible factor that may result in fewer detections of synthetic compounds in the urban-crystalline study area is that mountain communities generally are much younger than the towns on the plains. Tritium data also indicate that ground water in some parts of the urban-crystalline study area may be older than water in the other two study areas. Younger communities and older ground water equate to less likelihood that synthetic compounds will be detected. However, occasional large nitrate concentrations and presence of isolated VOC's in ground water in the urban-crystalline study area indicate that the water resources in this area are vulnerable to water-quality degradation and, with time and increasing population, greater degradation might occur.

The primary water-quality concerns identified in the urban-crystalline study area probably were the result of natural interactions between ground water and uranium-bearing minerals prevalent in the crystalline bedrock aquifer. Large uranium and radon concentrations were measured in wells throughout the study area. Uranium concentrations exceeded the proposed 20-μg/L national drinking-water standard in 10 of 27 wells sampled; the highest concentration of uranium measured for any well sampled in the three South Platte River Basin study areas (156 μg/L) was from the urban-crystalline study area. Radon concentrations in water samples from the urban-crystalline study area (median = 4,400 pCi/L) were large compared to the national average of 350 pCi/L (Paulsen, 1991). Radon concentrations as high as 3,000,000 pCi/L have been measured in ground water in the crystalline bedrock aquifer near Lyons, Colo. (Schumann, 1993). A risk assessment for radon in drinking water currently is underway by the National Academy of Sciences (U.S. Environmental Protection Agency, 1996a). The EPA would use this risk assessment to establish an MCL for radon. If the MCL for radon is low, or the proposed MCL for uranium is finalized, the use of ground water from the crystalline bedrock aquifer would almost certainly be affected.

## Urban-Alluvium Study Area

The urban-alluvium study area was inside the boundary of the largest metropolitan area in Colorado, located at the transition between the mountains and the plains. Ground-water quality in this setting was expected to be very vulnerable to degradation from urban land-use activities due to the high population density, relatively shallow water table, and large hydraulic conductivities of the alluvial aquifer.

Ground-water quality in the urban-alluvium study area was characterized by larger concentrations of most water-quality constituents than measured in the urban-crystalline study area. Dissolved-solids and nutrient concentrations were larger in the urban-alluvium study area, VOC's and pesticides were more widely distributed, and some trace-element concentrations were larger with selected trace elements detected only in the urban-alluvium study area.

The larger concentration of dissolved solids in the urban-alluvium study area compared to the urban-crystalline study area probably was a partial result of rock/water interactions and anthropogenic effects. The sedimentary rock units in the plains part of the South Platte River Basin have minerals that are more easily dissolved than those in the crystalline bedrock aquifer of the mountains. In the continuum of water flow from the mountains to the plains, several different sedimentary rock units exist between the urban-crystalline and the urban-alluvium study areas. These sedimentary rock units contribute dissolved solids to the ground- and surface-water systems.

Also important to the concentration of dissolved solids in the urban-alluvium study area are the effects of the urban land-use setting in metropolitan Denver. High population density in the urban-alluvium study area increases the potential sources of synthetic constituents. Urban runoff from precipitation, lawn irrigation, and many other sources recharge the alluvial aquifer, washing anthropogenic constituents into the ground water. Water from the South Platte River, which is partially derived from treated urban wastewater, flows in and out of the alluvial aquifer. Evaporative concentration of dissolved solids during water reuse also increases the concentrations of dissolved solids in the ground water of the urban-alluvium study area.

Nitrate concentrations in the urban-alluvium study area also are affected by the urban land-use setting. Nitrate sources in the urban-alluvium study area are numerous, including sewage disposal, fertilizers, and domestic animals. However, nitrate concentrations in this study area appear to be somewhat attenuated in wells where VOC's are present. The urban-alluvium study area had a large number of water samples from wells (about 86 percent) in which VOC's were detected (fig. 8). The presence of VOC's in the urban-alluvium study area has been correlated with anaerobic conditions in the alluvial aquifer (Bruce and McMahon, 1996). Anaerobic conditions increase the likelihood of larger ammonium concentrations and denitrification, a microbial process that reduces nitrate concentrations. Several water samples that contained VOC's had elevated ammonium concentrations (fig. 7*B*). In the absence of VOC's, larger nitrate concentrations might have been measured. Ammonium can later be converted to nitrate if oxygen becomes available.

The occurrence of VOC's in shallow ground water of the South Platte River Basin is apparently associated with urban land-use settings and high population density. VOC's were detected in the urban-crystalline and urban-alluvium study areas. There were no detections of VOC's in the agricultural-alluvium study area. The high frequency of detections and occasional large concentrations of VOC's in the urban areas of the South Platte River Basin indicate a predominant anthropogenic effect on ground-water quality by the urban land-use environment. This is thought to be a result of the high volume of VOC's stored and used in urban areas. Bruce and McMahon (1996) discuss the occurrence and distribution of VOC's in ground water of the urban-alluvium study area in greater detail. VOC's in ground water of the urban-alluvium study area affected the concentrations of other redox-sensitive ground-water constituents including major ions, nutrients, and trace elements by inducing changes in the oxidation/reduction conditions in that environment during microbial metabolism of the organic compounds.

The fact that MTBE was the most frequently detected VOC in the urban-crystalline and urban-alluvium study areas is noteworthy given that this compound has only been part of the local gasoline supply since the mid- to late-1970's. An atmospheric source of MTBE to local ground water was suggested by Bruce and McMahon (1996). Chlorinated solvents also were detected in both urban study areas, indicating the widespread occurrence of these constituents in more densely populated areas.

Pesticide detections in 90 percent of the wells sampled in the urban-alluvium study area indicate another water-quality effect associated with the urban land-use setting. Although the concentrations of detected pesticides were low, these compounds appear to be widespread and persistent. The detection of the pesticide dieldrin in ground water from the urban-alluvium and agricultural-alluvium study areas indicates the persistence of some pesticides in the environment. Dieldrin is an insecticide for which use was suspended in the United States in 1975 (U.S. Environmental Protection Agency, 1990). The presence of dieldrin in these study areas (1993–94) indicates an approximate life span of at least 20 years. The persistence of pesticide compounds in the environment may lead to increasing concentrations in these study areas over time.

The specific pesticide compounds detected in the urban-alluvium study area can be correlated with the urban land-use setting. In the urban-alluvium study area, the five most frequently detected pesticides (table 14) are all used in urban settings. The herbicide prometon was by far the most frequently detected pesticide, occurring in 24 of 30 wells sampled. Prometon is a nonselective soil sterilant recommended for use in noncrop areas (Ciba-Geigy, 1991). Application of prometon as advertised will guarantee that no vegetation will grow in the area of application for 1 year or longer. Prometon is used to control vegetation along roadways and in industrial and commercial areas. It occasionally is incorporated into asphalt pavement to enhance the longevity of this surface cover (Ciba-Geigy, 1991). Atrazine and simazine were the second most frequently detected pesticides, each being detected in 7 of 30 wells in the urban-alluvium study area. Although the compound atrazine most commonly is used in agricultural areas to control weed growth in many varieties of corn, it also is applied by licensed professionals in urban turf areas to control broadleaf grasses and weeds. Simazine, another nonselective herbicide, is used in high concentrations as a soil sterilant in industrial and commercial areas or in low concentrations to control broadleaf weeds and grasses in turf grass, lawns, ornamental and tree nursery stocks, and in ponds to control algae and weeds. The compound deethylatrazine is a breakdown product of atrazine. Tebuthiuron, another herbicide detected in the urban-alluvium study area, is used to control woody vegetation in noncropland areas, such as along highways, pipelines, railroads, and ditch banks, as well as in open areas, such as industrial sites, pasture, and rangeland.

Although no pesticides were detected in the urban-crystalline study area in the mountainous part of the basin, the presence of VOC's in the urban-crystalline study area indicates that the crystalline bedrock aquifer also is vulnerable to the same effects of urban land use as determined for the urban-alluvium study area. It is, therefore, possible that with increasing time and development of the mountain urban areas, pesticides eventually may be detected in the crystalline bedrock aquifer as they were in the urban-alluvium study area in metropolitan Denver.

Uranium and radon concentrations were relatively large in the urban-alluvium study area and, as in the urban-crystalline study area, probably represent a naturally derived water-quality concern. The median uranium concentration increased slightly from the urban-crystalline study area to the urban-alluvium study area (table 15). The median radon concentration was smaller in the urban-alluvium study area (1,100 pCi/L) compared to 4,400 pCi/L in the urban-crystalline study area, but was still greater than the national average of 350 pCi/L. Bruce and McMahon (1996) correlated the largest uranium and radon concentrations in the urban-alluvium study area to one specific stream drainage. This stream drains directly from the mountains to the west of the urban-alluvium study area and is, therefore, in close proximity to the bedrock source of uranium-bearing minerals. The predominant control on the presence of uranium and radon in urban-crystalline and urban-alluvium study areas probably is the mineral composition of the aquifers, not the urban land-use setting.

## Agricultural-Alluvium Study Area

The setting in the agricultural-alluvium study area was the most intensely cultivated and irrigated agricultural area in the South Platte River Basin. Corn was the predominant crop over much of this study area. The alluvial aquifer in this study area basically is the same aquifer sampled in the urban-alluvium study area and has a shallow water table and sediments with large hydraulic conductivities.

The agricultural-alluvium study area is located at the downstream end of the water-flow continuum described in this report. The resulting chemical evolution of water quality, as water flows through the South

Platte River Basin, is represented by the cluster of water types determined for the agricultural-alluvium study area (fig. 5) and the larger concentrations of dissolved solids also measured in this study area compared to the other study areas (fig. 6).

Even within the length of the agricultural-alluvium study area, a downstream trend of increasing dissolved solids can be observed. The increase in dissolved solids in the downstream direction likely reflects the cumulative effect of water reuse and evaporative concentration of dissolved constituents. In the agricultural-alluvium study area, surface water is diverted for crop irrigation where it recharges the alluvial aquifer and is subsequently recycled through irrigation wells. Eventually, ground water discharges to the South Platte River where it is again diverted for crop irrigation. Reuse of water as it flows through the agricultural-alluvium study area causes evaporative concentration of salts in the near-surface soils, and these salts, along with synthetic compounds applied to crops, are available to be washed into the shallow ground water.

The primary water-quality concerns identified in the agricultural-alluvium study area were large concentrations of dissolved solids, large nitrate concentrations, widespread occurrence of pesticides, and large uranium concentrations. Unlike the urban-crystalline and urban-alluvium study areas, there were no VOC's detected in water samples from the agricultural-alluvium study area.

The downstream increase in dissolved solids in shallow ground water of the South Platte River Basin can be correlated with an increase in sulfate concentrations (fig. 12). The percentage of the dissolved solids consisting of sulfate for the data sets from each of the three ground-water study areas is shown in figure 13*A*. Sulfate in the agricultural-alluvium study area on the eastern plains replaces bicarbonate ($HCO_3$), which was the dominant anion in ground water in the urban-crystalline study area (fig. 13*B*). This shift to sulfate as the dominant anion partly is due to human effects from fertilizer applications and urban wastewater discharge and partly to interactions with sulfur-bearing rock units.

Large nitrate concentrations also were measured in the agricultural-alluvium study area. Nitrate concentrations exceeding the recommended drinking-water standard of 10 mg/L as nitrogen have been well documented in alluvial ground water of the agricultural areas in the South Platte River Basin (Austin, 1993; McMahon and Bohlke 1996). Large nitrate concentrations in the agricultural-alluvium study area generally have been attributed to application of fertilizers and manure. Nitrate concentrations were largest

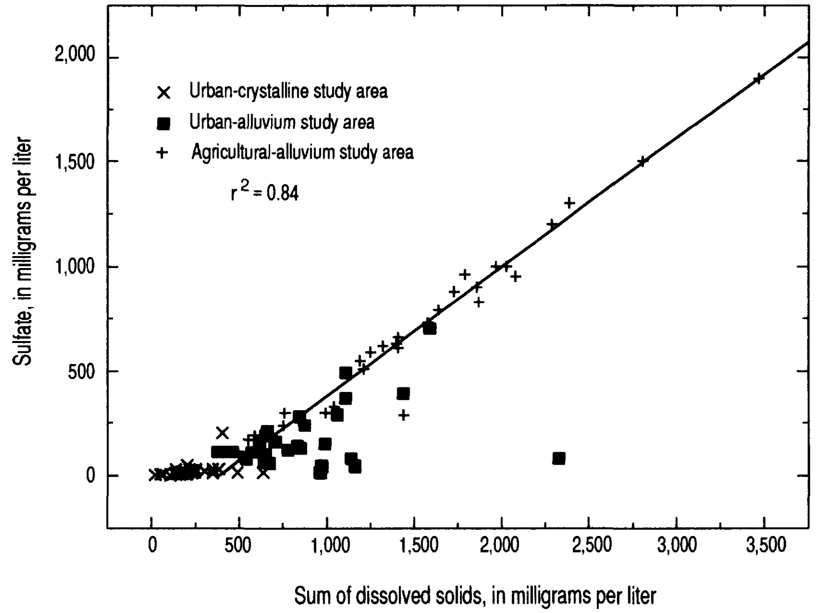


**Figure 12.** Relation of concentration of dissolved solids to concentration of sulfate in three study areas in the South Platte River Basin, 1993–95.

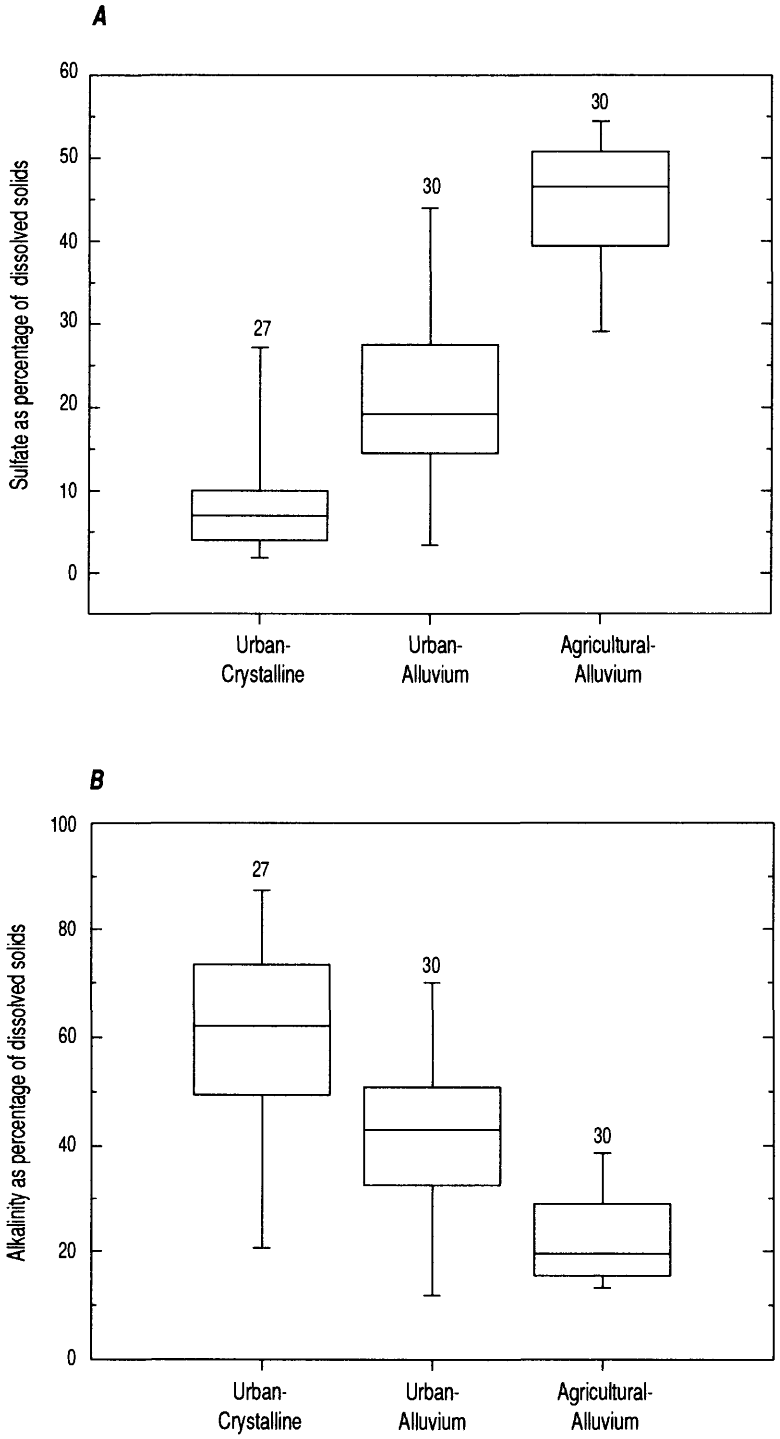


**Figure 13.** Box plots showing (*A*) sulfate concentrations as percentage of dissolved solids, and (*B*) alkalinity (as calcium carbonate) as percentage of dissolved solids in three study areas in the South Platte River Basin, 1993–95.

in the western, upstream end of the agricultural-alluvium study area and generally decreased in a downstream direction. The western end of the agricultural-alluvium study area has broader alluvial deposits and more irrigated agricultural land than the eastern end of the study area. Larger nitrate concentrations in ground water correlated with the more intensely cultivated area.

Litke (1996) reported that concentrations of phosphorus in surface water of the South Platte River Basin have median concentrations that generally are much larger than those measured in ground water of the agricultural-alluvium study area. The larger phosphorus concentrations in surface water of the South Platte River Basin suggest that the phosphorus load mainly moves through the basin in the surface water. Contribution of phosphorus directly to surface water primarily was attributed to overland runoff and wastewater-treatment-plant discharges (Litke, 1996).

Pesticide compounds frequently were detected in the urban-alluvium and agricultural-alluvium study areas, generally with larger concentrations measured in the agricultural-alluvium study area (fig. 10). The large number of pesticide detections in the urban-alluvium and agricultural-alluvium study areas probably are related to the intensity of land use rather than the commonality of the alluvial aquifer.

A correlation also can be made between the type of pesticide compounds detected and the land-use setting in a given study area. As previously mentioned, the pesticide compounds detected in the urban-alluvium study area were consistent with those used in the urban environment. In the agricultural-alluvium study area, the five most frequently detected pesticide compounds, listed in order, were deethylatrazine, atrazine, prometon, metolachlor, and simazine (table 14). These compounds were each detected in five or more wells in the agricultural-alluvium study area. Atrazine and its breakdown product deethylatrazine were detected in almost every well in the agricultural-alluvium study area. Atrazine mainly is used to control weeds in corn, which is the crop with greatest production yield in the South Platte River Basin. The fact that the atrazine breakdown product, deethylatrazine, was so frequently detected indicates a history of atrazine use in this study area. The large number of wells in the agricultural-alluvium study area that contained the pesticide prometon (23 of 30 wells) was not expected because prometon generally is for noncrop use. Prometon may be applied in agricultural areas along rights-of-way, around barnyards, and occasionally in ditches to keep them free of vegetation; however, the amount of these applications was reported to be minimal compared to the urban land-use setting. Metolachlor and dilute simazine mixtures are popular herbicides for agricultural weed control in corn and other crops. Many of the pesticides detected in the urban-alluvium and agricultural-alluvium study areas are among the most heavily used in the South Platte River Basin (Dennehy and others, 1995).

Although no detected pesticide exceeded an established MCL or HA, very little is known about the health effects of exposure to multiple pesticides at low concentrations. The presence of dieldrin in both the urban-alluvium and agricultural-alluvium study areas is evidence of the potential for persistence of some of these compounds in the environment. Atrazine was expected to be present in the alluvial ground water of the agricultural-alluvium study area because it is applied primarily to corn. Atrazine also was detected in 7 of 30 wells in the urban-alluvium study area where use of this compound is carefully restricted. Prometon, a nonagricultural pesticide was frequently detected in the agricultural-alluvium study area. These findings indicate the difficulty in keeping pesticide compounds out of the ground water, even in areas with minimal use and restrictive controls.

Downstream trends in the concentrations of selected trace elements is evident in the ground water of the South Platte River Basin. There is a correlated increase in the median concentrations of arsenic, selenium, and uranium from the urban-crystalline study area in the western mountains to the agricultural-alluvium study area on the eastern plains (fig. 11*C*–11*E*). The downstream increase in ground-water concentrations of these constituents may be attributed to longer residence time of water in the basin and greater evaporative concentration. However, larger concentrations in the agricultural-alluvium study area appear to be partially derived from local natural sources (Boberg and Runnells, 1971). Although granitic bedrock in the urban-crystalline study area, granitic rock fragments in the alluvial sediments, and phosphate fertilizers applied in the agricultural areas are all potential sources for these constituents, data collected in the agricultural-alluvium study area indicate that a significant source may be the Cretaceous Pierre Shale rock unit that underlies the alluvial aquifer in the central part of the basin.

Preliminary water-quality and aquifer-sediment data collected at the shale/alluvium interface near Fort Morgan, Colo., suggest that leaching of arsenic, selenium, and uranium from the Pierre Shale may comprise a substantial contribution of these constituents to the alluvial ground water. The data also suggest that organic compounds, sulfur species, and nutrients might be affected by chemical processes at this shale/alluvium interface, resulting in a source or a sink of these constituents to the alluvial ground water.

Although radon-222 is derived from the radioactive decay of uranium-238, data indicate an inverse relation between the concentrations of uranium and radon from the three study areas (fig. 11*E* and 11*F*). However, there is no significant correlation between uranium and radon concentrations when paired analyses are plotted against each other. The lack of correlation between uranium and radon concentrations probably is due to the very different chemical and reactive nature of the two elements. Also, the depth to water in the alluvial aquifer generally is much less than that reported for the wells sampled in the crystalline bedrock aquifer, allowing for the possibility of degassing of radon to the atmosphere from the alluvial sediments.

## SUMMARY

During 1993–95, the occurrence, distribution, and range of concentrations for about 170 water-quality constituents was evaluated for three study areas in the South Platte River Basin. The study focused on combinations of specific land-use settings and unconfined aquifer units; an urban setting over a crystalline bedrock aquifer, an urban setting over an unconsolidated alluvial aquifer, and an agricultural setting over an unconsolidated alluvial aquifer. Ground-water quality in the urban-crystalline, urban-alluvium, and agricultural-alluvium study areas in the South Platte River Basin is the result of several factors, including the mineralogy of aquifer material and other rock units in the basin, the differences in land-use practices in each study area, and the reuse of the limited water supply as it flows through the basin. These factors can combine to yield varying results for ground-water quality.

In the urban-crystalline study area in the mountainous part of the basin, an estimated 60 to 70 percent of the households (about 54,000 to 63,000 people) rely on the crystalline bedrock aquifer as the primary source of drinking water. The ground water in this study area generally has small dissolved-solids concentrations and few synthetic compounds. Small nitrate concentrations in the urban-crystalline study area indicate that nitrate contamination is not currently a widespread water-quality concern, as might have been anticipated by the large number of leach field septic systems. Nitrate contamination in the urban-crystalline study area appears to be site specific.

Evidence of human effects on shallow ground-water quality in the urban-crystalline study area was indicated by isolated detections of VOC's. The concentrations of detected VOC's were small; however, these limited detections indicate that the ground water in this study area is vulnerable to land-use effects. No pesticide compounds were detected in the ground water of the urban-crystalline study area. The primary water-quality concerns observed in the urban-crystalline study area were large uranium and radon concentrations, which are derived from natural sources. Uranium has a proposed MCL, and radon is being evaluated by the National Academy of Sciences for the EPA in order to establish a drinking-water standard. Concentrations of uranium and radon were sufficiently large that, should low-concentration drinking-water standards be finalized, use of drinking water from the crystalline bedrock aquifer likely would be affected.

In the urban-alluvium study area in metropolitan Denver, anthropogenic effects on ground-water quality were represented by larger concentrations of most water-quality constituents than measured in the urban-crystalline study area. Dissolved-solids concentrations were greater than those measured in the urban-crystalline study area. Nitrate concentrations also were larger in the urban-alluvium study area, occasionally exceeding EPA drinking-water MCL's. Pesticides (detected in 90 percent of wells) and VOC's (detected in 86 percent of wells) were frequently detected in the shallow ground water of the urban-alluvium study area, and these compounds are the primary water-quality concerns of this study area. Large amounts of pesticides and VOC's are stored and used in this urban area making it likely that these types of compounds would be present in the shallow ground water. VOC concentrations occasionally exceeded EPA drinking-water MCL's or HA's; pesticide concentrations never exceeded the drinking-water MCL's or HA's. Some pesticide compounds appear to be persistent in the ground water of this study area, as indicated by the detection of dieldrin, a compound whose use was suspended about 2 decades ago.

Large uranium and radon concentrations also were measured in the urban-alluvium study area. Uranium concentrations often exceeded the proposed MCL. Although the water from this aquifer generally is not used for drinking water, finalizing the MCL's at the proposed levels may affect the future use and value of water in this aquifer.

In the agricultural-alluvium study area, concentrations of dissolved solids were the largest measured in the three study areas, indicating a downstream trend of increasing dissolved solids. Water reuse and evaporative concentration of salts lead to increasing dissolved solids as water flows through the basin. The increase in dissolved solids is correlated with an increase in the sulfate anion. Sulfate replaces bicarbonate as the predominant anion in ground water as water flows from the mountains to the plains.

High nitrate concentrations and widespread pesticides also were identified as primary ground-water-quality concerns in the agricultural-alluvium study area. Nitrate concentrations exceeded EPA drinking-water MCL's in 14 of 30 wells sampled in this study area. Nitrate concentrations generally were larger in the western part of the agricultural-alluvium study area. Pesticides were detected in 29 of 30 wells sampled in this study area. Pesticide concentrations were small compared to MCL's and HA's; however, several water samples contained multiple pesticides. The detection of the pesticide dieldrin in the agricultural-alluvium study area indicates the persistence of some pesticides in the environment. There were no detections of VOC's in this study area.

Large concentrations of uranium and radon also were measured in the agricultural-alluvium study area. The occurrence of these compounds at large concentrations is common to all three ground-water study areas in the South Platte River Basin. Background concentrations of uranium and radon probably are large in much of the shallow ground water throughout the South Platte River Basin. Large uranium and radon concentrations throughout the South Platte River Basin might be the most significant finding of the three land-use/aquifer studies. If the proposed regulatory limits are finalized, the future use of the ground water in these aquifers as a drinking-water resource might be affected.

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