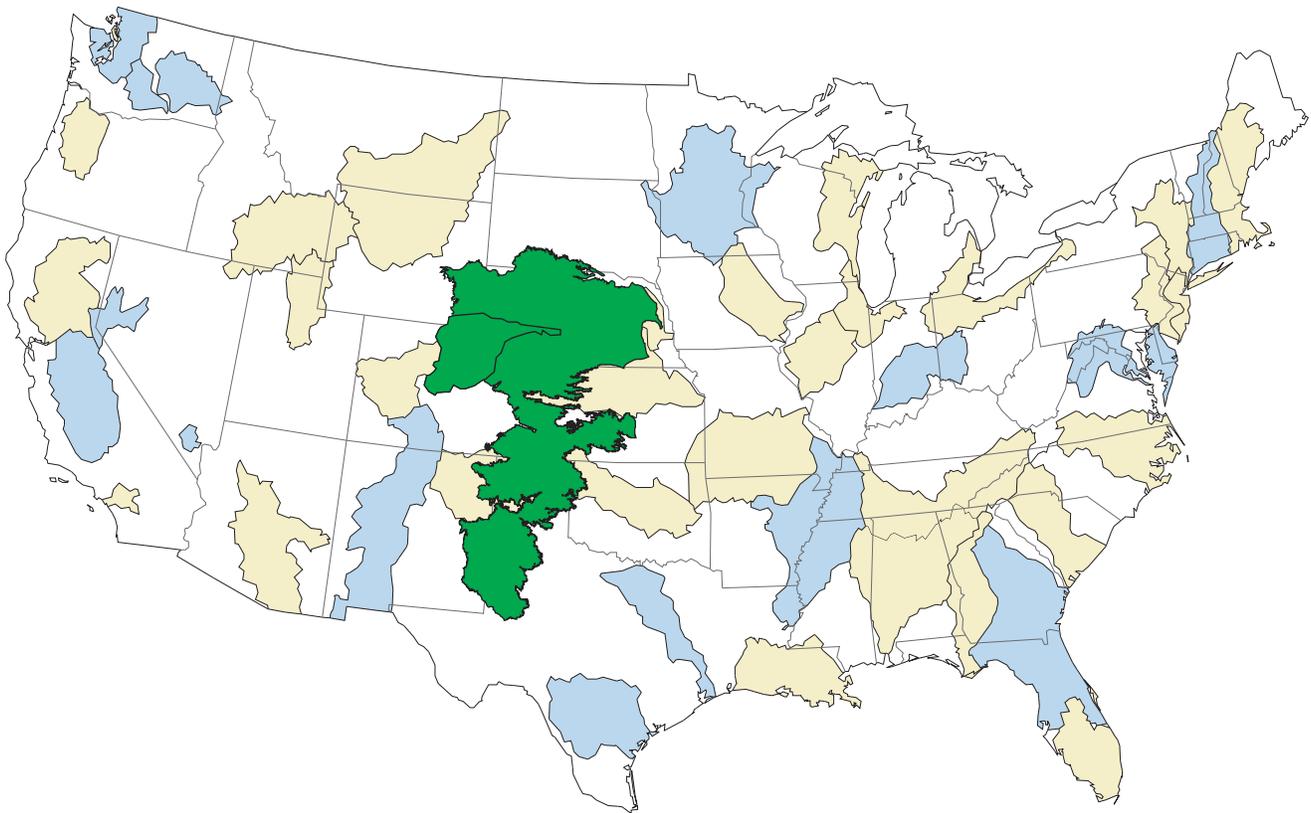


Occurrence of Selected Organic Compounds in Groundwater Used for Public Supply in the Plio-Pleistocene Deposits in East-Central Nebraska and the Dawson and Denver Aquifers near Denver, Colorado, 2002–2004



Scientific Investigations Report 2008–5243

Cover. Location of National Water-Quality Assessment (NAWQA) study units, High Plains Regional Groundwater and South Platte River Basin study units, and Source Water-Quality Assessment study areas.

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By Jeffrey B. Bails, Benjamin J. Dietsch, Matthew K. Landon, and Suzanne S. Paschke

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

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KEN SALAZAR, Secretary

U.S. Geological Survey
Suzette M. Kimball, Acting Director

U.S. Geological Survey, Reston, Virginia: 2009

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Foreword

The U.S. Geological Survey (USGS) is committed to providing the Nation with credible scientific information that helps to enhance and protect the overall quality of life and that facilitates effective management of water, biological, energy, and mineral resources (<http://www.usgs.gov>). Information on the Nation's water resources is critical to ensuring long-term availability of water that is safe for drinking and recreation and is suitable for industry, irrigation, and fish and wildlife. Population growth and increasing demands for water make the availability of that water, now measured in terms of quantity and quality, even more essential to the long-term sustainability of our communities and ecosystems.

The USGS implemented the National Water-Quality Assessment (NAWQA) Program in 1991 to support national, regional, State, and local information needs and decisions related to water-quality management and policy (<http://water.usgs.gov/nawqa>). The NAWQA Program is designed to answer: What is the condition of our Nation's streams and groundwater? How are conditions changing over time? How do natural features and human activities affect the quality of streams and groundwater, and where are those effects most pronounced? By combining information on water chemistry, physical characteristics, stream habitat, and aquatic life, the NAWQA Program aims to provide science-based insights for current and emerging water issues and priorities. From 1991–2001, the NAWQA Program completed interdisciplinary assessments and established a baseline understanding of water-quality conditions in 51 of the Nation's river basins and aquifers, referred to as Study Units (<http://water.usgs.gov/nawqa/studyu.html>).

Multiple national and regional assessments are ongoing in the second decade (2001–2012) of the NAWQA Program as 42 of the 51 Study Units are reassessed. These assessments extend the findings in the Study Units by determining status and trends at sites that have been consistently monitored for more than a decade, and filling critical gaps in characterizing the quality of surface water and groundwater. For example, increased emphasis has been placed on assessing the quality of source water and finished water associated with many of the Nation's largest community water systems. During the second decade, NAWQA is addressing five national priority topics that build an understanding of how natural features and human activities affect water quality, and establish links between sources of contaminants, the transport of those contaminants through the hydrologic system, and the potential effects of contaminants on humans and aquatic ecosystems. Included are topics on the fate of agricultural chemicals, effects of urbanization on stream ecosystems, bioaccumulation of mercury in stream ecosystems, effects of nutrient enrichment on aquatic ecosystems, and transport of contaminants to public-supply wells. These topical studies are conducted in those Study Units most affected by these issues; they comprise a set of multi-Study-Unit designs for systematic national assessment. In addition, national syntheses of information on pesticides, volatile organic compounds (VOCs), nutrients, selected trace elements, and aquatic ecology are continuing.

The USGS aims to disseminate credible, timely, and relevant science information to address practical and effective water-resource management and strategies that protect and restore water quality. We hope this NAWQA publication will provide you with insights and information to meet your needs, and will foster increased citizen awareness and involvement in the protection and restoration of our Nation's waters.

The USGS recognizes that a national assessment by a single program cannot address all water-resource issues of interest. External coordination at all levels is critical for cost-effective management, regulation, and conservation of our Nation's water resources. The NAWQA Program, therefore, depends on advice and information from other agencies—Federal, State, regional, interstate, Tribal, and local—as well as nongovernmental organizations, industry, academia, and other stakeholder groups. Your assistance and suggestions are greatly appreciated.

Matthew C. Larsen
Associate Director for Water

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Conversion Factors and Datums

Multiply	By	To obtain
Length		
inch (in.)	2.54	centimeter (cm)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
mile, nautical (nmi)	1.852	kilometer (km)
yard (yd)	0.9144	meter (m)
Area		
acre	4,047	square meter (m ²)
square foot (ft ²)	0.09290	square meter (m ²)
square inch (in ²)	6.452	square centimeter (cm ²)
square mile (mi ²)	2.590	square kilometer (km ²)
Volume		
ounce, fluid (fl. oz)	0.02957	liter (L)
pint (pt)	0.4732	liter (L)
quart (qt)	0.9464	liter (L)
gallon (gal)	3.785	liter (L)
gallon (gal)	0.003785	cubic meter (m ³)
million gallons (Mgal)	3,785	cubic meter (m ³)
cubic inch (in ³)	16.39	cubic centimeter (cm ³)
cubic inch (in ³)	0.01639	liter (L)
cubic foot (ft ³)	0.02832	cubic meter (m ³)
acre-foot (acre-ft)	1,233	cubic meter (m ³)

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

$$^{\circ}\text{F}=(1.8\times^{\circ}\text{C})+32$$

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

$$^{\circ}\text{C}=(^{\circ}\text{F}-32)/1.8$$

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

Vertical coordinate information is referenced to the National Geodetic Vertical Datum of 1929 (NGVD 29).

Horizontal coordinate information is referenced to the North American Datum of 1983 (NAD 83).

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

Occurrence of Selected Organic Compounds in Groundwater Used for Public Supply in the Plio-Pleistocene Deposits in East-Central Nebraska and the Dawson and Denver Aquifers near Denver, Colorado, 2002–2004

By Jeffrey B. Bails, Benjamin J. Dietsch, Matthew K. Landon, and Suzanne S. Paschke

Abstract

The National Water-Quality Assessment Program of the U.S. Geological Survey has an ongoing Source Water-Quality Assessment program designed to characterize the quality of water in aquifers used as a source of drinking-water supply for some of the largest metropolitan areas in the Nation. In addition to the sampling of the source waters, sampling of finished or treated waters was done in the second year of local studies to evaluate if the organic compounds detected in the source waters also were present in the water supplied to the public.

An evaluation of source-water quality used in selected groundwater-supplied public water systems in east-central Nebraska and in the south Denver metropolitan area of Colorado was completed during 2002 through 2004. Fifteen wells in the Plio-Pleistocene alluvial and glacial deposits in east-central Nebraska (the High Plains study) and 12 wells in the Dawson and Denver aquifers, south of Denver (the South Platte study), were sampled during the first year to obtain information on the occurrence and distribution of selected organic chemicals in the source waters. During the second year of the study, two wells in east-central Nebraska were resampled, along with the associated finished water derived from these wells, to determine if organic compounds detected in the source water also were present in the finished water. Selection of the second-phase sampling sites was based on detections of the most-frequently occurring organic compounds from the first-year Source Water-Quality Assessment study results. The second-year sampling also required that finished waters had undergone water-quality treatment processes before being distributed to the public.

Sample results from the first year of sampling groundwater wells in east-central Nebraska show that the most-frequently detected organic compounds were the pesticide atrazine and its degradate, deethylatrazine (DEA, otherwise known as 2-chloro-4-isopropylamino-6-amino-s-triazine or CIAT), which

were detected in 9 of the 15 wells (60 percent of the samples). The second most frequently detected organic compound was tetrachloroethylene, detected in 4 of the 15 wells (27 percent of the samples), followed by chloroform, trichloroethylene, and 2-hydroxyatrazine (2-hydroxy-4-isopropylamino-6-ethylamino-s-triazine, or OIET), present in 3 of the 15 wells (20 percent of the samples). The pesticide compounds deisopropylatrazine (2-chloro-6-ethylamino-4-amino-s-triazine, or CEAT), metolachlor, and simazine and the volatile organic compound *cis*-1,2-dichloroethylene were detected in 2 of the 15 wells, and the compounds diuron and 1,2-dichloroethane were detected in only 1 of the 15 wells during the first-year sampling. Most detections of these compounds were at or near the minimum reporting levels, and none were greater than their regulatory maximum contaminant level.

There were few detections of organic compounds during the first year of sampling groundwater wells in the South Platte study area. The compounds atrazine, deethylatrazine, picloram, tetrachloroethylene, methyl-*tert*-butyl-ether (MTBE), tris(2-butoxyethyl)phosphate, and bromoform were detected only once in all the samples from the 12 wells. Most detections of these compounds were at or near the minimum reporting levels, and none were greater than their regulatory maximum contaminant level.

Second-year sampling, which included the addition of paired source- and finished-water samples, was completed at two sites in the High Plains study area. Source-water samples from the second-year sampling had detections of atrazine and deethylatrazine; at one site deisopropylatrazine and chloroform also were detected. The finished-water samples, which represent the source water after blending with water from other wells and treatment, indicated a decrease in the concentrations of the pesticides at one site, whereas concentrations remained nearly constant at a second site. The trihalomethanes (THMs or disinfection byproducts), chloroform, bromoform, bromodichloromethane, and dibromochloromethane were detected in all finished-water samples and are a result of the

chlorine added during treatment reacting with organics in the source waters. Finished waters at one site also contained concentrations of organic compounds not present in the source-water sample, indicating that other wells may be contributing compounds to the finished waters.

When comparing the source-water data from both studies, the more frequent detection and higher concentrations of pesticides and pesticide degradation byproducts in the High Plains wells are an indication that the agricultural land-use setting near these wells has affected source-water quality to a greater extent than the rangeland setting historically surrounding the Colorado wells. Land use near the Colorado public-supply wells is shifting from rangeland to an urban environment that may eventually affect groundwater quality; however, the potential effects of this transition on water quality currently (2004) are not expressed in the sampled source water.

Results from the High Plains and South Platte studies in Nebraska and Colorado also were compared to similar studies done in Utah and Nevada to provide a larger-scale perspective on the quality of source waters and the effects from other land-use settings. Whereas groundwater-quality data from the Utah and Nevada studies were similar to each other, frequency of detections and concentrations for a majority of the compounds were intermediate to those of the High Plains and South Platte studies. These results indicate that the long history of agricultural land use and the more permeable alluvial deposits in Nebraska are affecting the source-water quality, whereas the potential effects of developing urbanization on source-water quality in the deep Dawson and Denver bedrock aquifers near Denver, Colorado, are not yet apparent.

Introduction

In 1991 the U.S. Geological Survey (USGS) began full implementation of the National Water-Quality Assessment (NAWQA) Program as a way to provide nationally consistent information on the physical, chemical, and biological condition of a representative set of the Nation's most densely populated river basins. The NAWQA program also has the goals of understanding the long-term trends in water quality and the primary factors that control the observed water-quality conditions (Gilliom and others, 1995). The emphasis during the first decade of the NAWQA Program (1991–2000) was on assessing the current status of water-quality conditions within the United States. Beginning in 2001, the NAWQA program began its second decade of intensive water-quality assessments and shifted to a greater emphasis on the study of trends in water quality and the primary processes controlling water-quality conditions (Mallard and others, 1999). During this second decade of the NAWQA program, 42 of the initial 52 study units evaluated during the first 10 years will be studied.

One of the investigative components for the second decade of the NAWQA program is the study of the occurrence and fate of natural and anthropogenic contaminants in

groundwater aquifers and streams used as primary drinking-water sources for municipal suppliers in major metropolitan areas. These studies, termed "Source Water-Quality Assessments (SWQA)," evaluated the status of source-water quality of Community Water Systems (CWS) on a local and regional scale in areas suspected or known to have degraded water quality because of natural or anthropogenic factors. Source water in the context of this report is defined as raw (untreated) water taken directly from the local groundwater aquifer or stream. Source-water quality information was collected to develop a better understanding of the quality of the drinking-water supplies and to increase the monitoring of drinking-water sources to benefit local suppliers and regulatory authorities. The water-quality data and interpretation of the results will aid local and state policy makers with a more comprehensive data set representing these important groundwater resources.

Groundwater SWQA studies were conducted in 15 NAWQA study units across the country (fig. 1). The CWS wells sampled in each of these study areas produce water from what the USGS considers "principal aquifers"; hydrogeologic units that are significant contributors to the regional water supply (U.S. Geological Survey, 2003). To enhance the usefulness of data collected by the SWQA study, all studies were nested within the boundaries of other studies being conducted by the NAWQA program. The SWQA studies also fit within the NAWQA framework for large-scale comparisons of water quality within the Nation.

Two of the study units within the NAWQA program include the High Plains Regional Groundwater study, which started in 1998, and the South Platte River Basin study, which began its first phase of studies in 1991 (fig. 1). The High Plains study is unique in the NAWQA program as it focuses solely on groundwater resources and encompasses a much larger spatial scale than the typical NAWQA groundwater study. Studies of the chemical transport and transformation processes of potential groundwater contaminants also were a substantial part of the High Plains study. More information on the NAWQA program is given at the web address (<http://water.usgs.gov/nawqa/>), along with specific information on the High Plains Regional study at (<http://co.water.usgs.gov/nawqa/hpgw/>) and the South Platte River Basin study at (<http://co.water.usgs.gov/nawqa/splt/>). Implementation of SWQA studies in the High Plains and South Platte study areas (hereinafter referred to as the "High Plains study" and the "South Platte study," respectively) began in 2002 and were completed over 2 years.

Fifteen supply wells (sites) located within the boundary of the Plio-Pleistocene alluvial and glacial deposits in east-central Nebraska (fig. 2) were sampled as part of the High Plains study. In the second year of the High Plains study, 2 of the 15 wells were resampled, and 2 additional sites representing finished waters from the 2 resampled wells also were sampled to determine if compounds in the source waters were present in the finished waters. The two sites were selected because organic compounds detected in the source-water wells were the most frequently detected in SWQA studies across

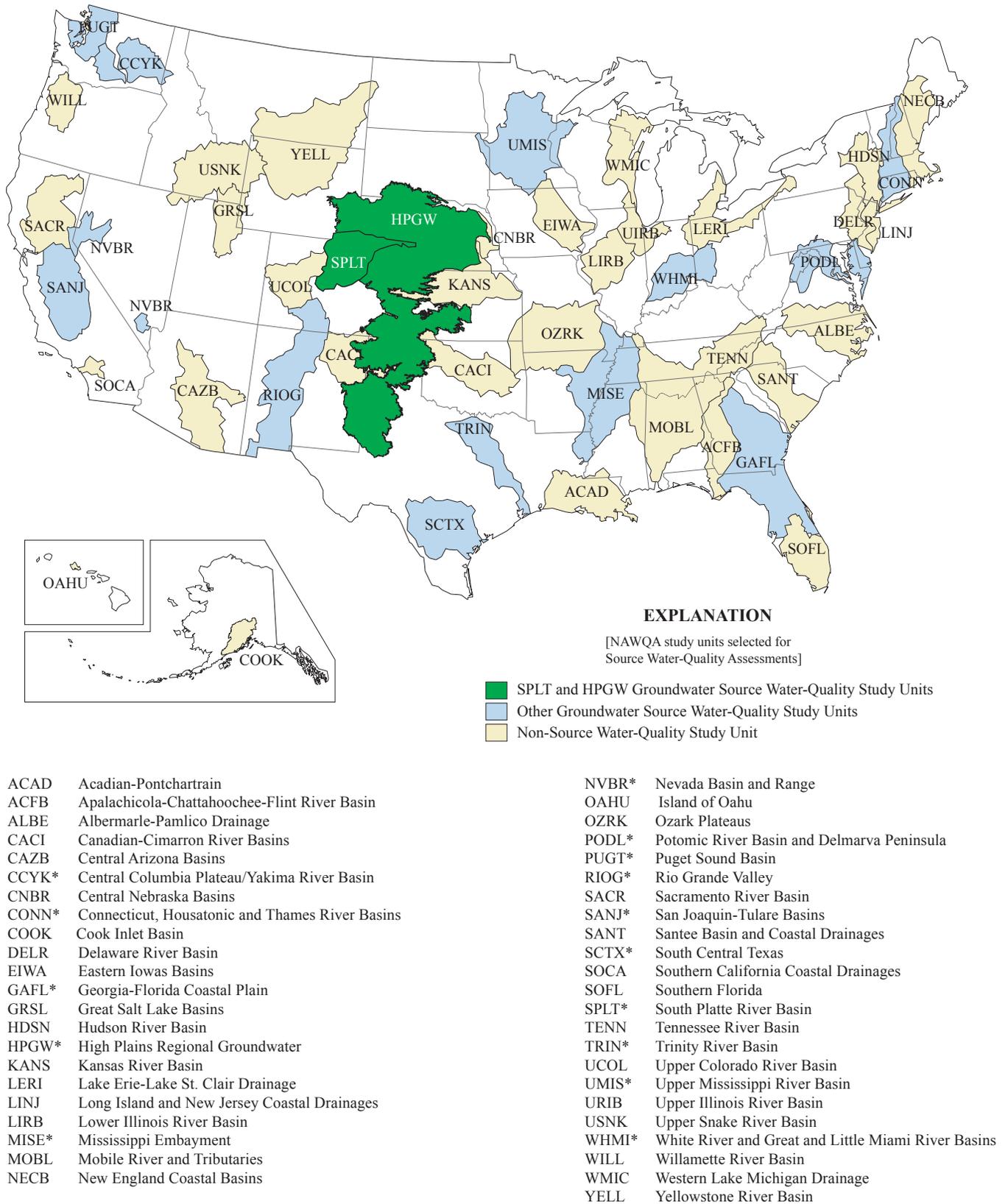
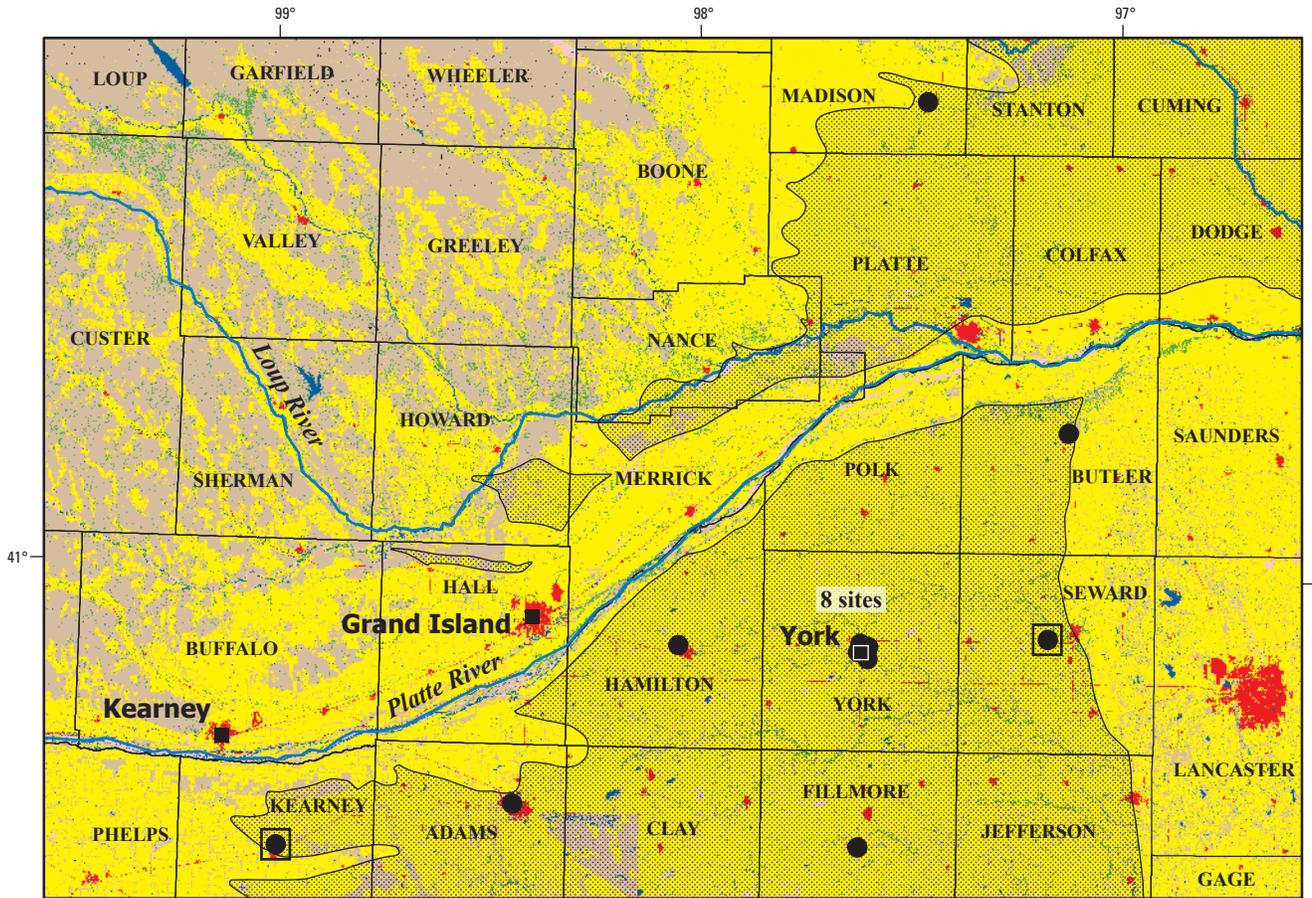
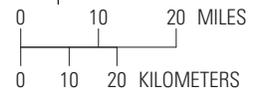


Figure 1. Location of National Water-Quality Assessment (NAWQA) study units, High Plains Regional Groundwater and South Platte River Basin study units, and Source Water-Quality Assessment study areas.



Base information from U.S. Geological Survey digital data, 1:24,000 and 1:100,000
 Land-cover data are 30-meter resolution from National Land-Cover Dataset (NLCD) 1992 data
 Albers Equal-Area projection
 Standard Parallels 29°30'N and 45°30'N, central meridian -96°00'W



EXPLANATION

- Land cover**
- Urban
 - Agriculture
 - Rangeland
 - Forest
 - Water
 - Wetlands
 - Barren
 - Extent of Plio-Pleistocene deposits
 - Supply well—One well unless otherwise noted
 - Supply well—Where source and finished waters sampled



Index map

Figure 2. Location and land use of the High Plains Regional Groundwater Source Water-Quality Assessment study area and sampled wells.

the Nation. In the context of this report, finished waters are defined as water that has passed through the CWS treatment process and are representative of the water being distributed to the community. Treatment at CWS may include blending of waters from multiple sources, in-line chlorination, and filtration.

The South Platte study was conducted in the south metropolitan area of Denver, Colorado (fig. 3). In this area many municipalities draw their water from the Dawson and Denver aquifers (S.S. Paschke, U.S. Geological Survey, written commun., 2006) which are the uppermost bedrock units of the Denver Basin aquifer system. Potential sites for this study spanned multiple municipalities, and because not all wells screened in the Dawson and Denver aquifers were being actively used during the period of the study, only 12 sites were available for sampling. Of the 12 sites, 8 sites are in Douglas County, 3 sites are in Arapahoe County, and the remaining site is in Elbert County. Because of the low number of detections and concentrations measured in the first year of sampling, there were no second-year samples collected for the South Platte study.

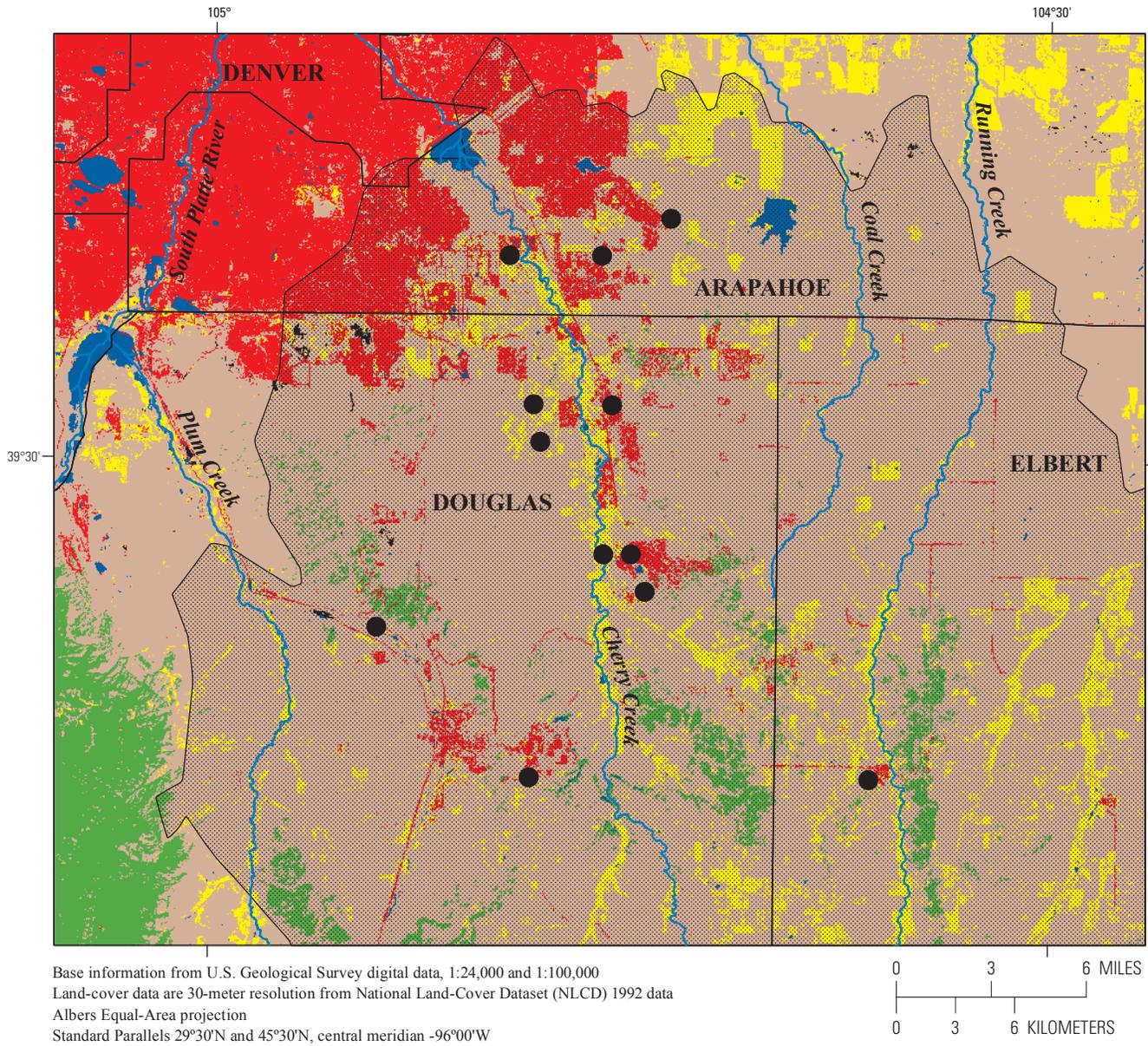
The purpose of this report is to present results from the High Plains and South Platte SWQA studies. Results characterize the occurrence and concentrations of several classes of organic compounds in groundwater resources that are used as primary drinking-water sources for municipalities in east-central Nebraska and the south Denver, Colorado, metropolitan area. This report describes, where available, observed differences between the qualities of untreated (source) and treated (finished) waters. Where applicable, comparisons between the studies outlined in this report are made in an effort to understand how the differences in current and historical land use and aquifer properties are reflected in groundwater quality.

Description of Study Areas

The High Plains and South Platte SWQA study areas are located within the Great Plains physiographic province (Fenneman and Johnson, 1946) of the west-central United States. The High Plains study area is within the boundaries of the Plio-Pleistocene alluvial and glacial deposits in east-central Nebraska, with sampled wells located in the following eight counties: Adams, Butler, Fillmore, Hamilton, Kearney, Madison, Seward, and York (fig. 2). The High Plains SWQA study area is in the northern part of the much larger High Plains aquifer system being studied by the High Plains Regional Groundwater study of the NAWQA program. Historically, the area in east-central Nebraska was used predominantly for irrigated agriculture. Data from the 2002 agricultural census showed that, for the total of 2.3 million acres of farmland in the eight Nebraska counties that contain wells included in this SWQA study, 58 percent of the area was used for growing corn, 35 percent was used to grow soybeans, 5 percent for hay, and 2 percent for wheat, oats, sorghum, and sunflower seeds (U.S. Department of Agriculture, 2004). In those same eight counties, the aggregated population data between 1990 and 2000 indicated a population increase of 4.7 percent, resulting in a population of 129,157 in 2000 (U.S. Census Bureau, 2006a, 2006b). County-specific population data between 1990 and 2000 indicated a population change ranging from a 6.6 percent decrease in Fillmore County to a 7.9 percent increase in Madison County. Incorporating 2004 population estimates, the average population change for all eight counties between 1990 and 2004 was a 4.8 percent increase. The 2004 estimates show one-half of the counties in Nebraska having decreasing populations from 2000 to 2004 (U.S. Census Bureau, 2006a).

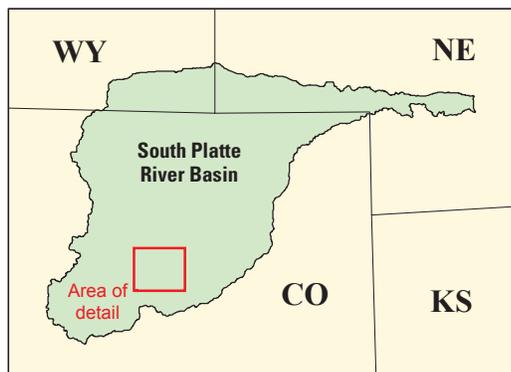
Selected Inorganic Constituents

In addition to the organic data collected at all the Source Water-Quality Assessment sites in this study, selected inorganic constituents also were part of the sampling regimen. Constituents of interest included arsenic, uranium, and nitrate. Arsenic and uranium are primarily derived by reaction processes between groundwater and the aquifer material itself, whereas elevated levels of nitrate in groundwater are most commonly derived from the application of fertilizers and from septic-tank leachate (McMahon and others, 2008). Data from the 15 source-water samples collected in the High Plains study area show one site with an arsenic concentration above the U.S. Environmental Protection Agency (USEPA) Maximum Contaminant Level (MCL) of 10 micrograms per liter ($\mu\text{g/L}$), three sites with uranium concentrations above the 30 $\mu\text{g/L}$ MCL, and one site with a nitrate concentration above the 10 milligrams per liter (mg/L) MCL (U.S. Environmental Protection Agency, 2003, 2004). Data from the 12 source-water samples collected in the South Platte study area indicate one site with uranium detected above the USEPA MCL. No inorganic analyses were completed on the finished-water samples in the High Plains study area, so no conclusion can be derived on the effectiveness of treatment for the removal of these contaminants; however, most community water systems monitor these compounds regularly and blend waters from many sources to keep concentrations less than any health-based risk level.



EXPLANATION

- Land cover**
- Urban
 - Agriculture
 - Rangeland
 - Forest
 - Water
 - Barren
 - Extent of Dawson aquifer
 - Supply well



Index map

Figure 3. Location and land-use of the South Platte River Basin Source Water-Quality Assessment study area and sampled wells.

The South Platte study area in the southern Denver metropolitan area of Colorado is within the boundaries of the Tertiary-aged Dawson aquifer and the underlying Cretaceous to Tertiary-aged Denver aquifer, which are the uppermost bedrock units of the larger Denver Basin aquifer system (fig. 3). This area, which includes parts of Arapahoe, Douglas, and Elbert Counties, has experienced a substantial population increase during the past decade and a subsequent shift from the predominantly native rangeland to high-density urban and suburban land use. In the three counties where SWQA sites were located, aggregated population data indicated a 48 percent population increase between 1990 and 2000, resulting in a population in the three Colorado counties of 683,605 (U.S. Census Bureau, 2006a, 2006b). Individual county data indicated population increases ranging from 25 percent in Arapahoe County to 191 percent in Douglas County. Incorporating 2004 estimated population data indicated a 70 percent increase in the population in all three counties between 1990 and 2004 (U.S. Census Bureau, 2006a, 2006b). Although both SWQA study areas lie within the same physiographic province, the substantial difference in land-use settings and population change allows for a comparison of the relative effects of different land uses on source-water quality.

Land and Water Use

Because the study areas as well as some of the well sites within each study area are separated by large distances, land-use statistics were calculated for each site to provide meaningful information on land-use differences. Land-use data were compiled for a circular buffer with a radius of 500 meters (1,640 feet) around each SWQA sample site. This area was expected to represent the land-use conditions likely to affect water quality in each well (Koterba, 1998). The most recent land-use data available in electronic format has a nominal date of 1992 and, therefore, cannot be considered current (U.S. Geological Survey, 1992). However, 1992 data give a historic assessment of land use, that when considered with more current population information, provides general indications of the recent transition in land-use settings. Generally, local land-use conditions will have a more pronounced effect on the water quality in a given well than regional land-use data (Koterba, 1998).

Land-use data around the wells in the High Plains study area were aggregated to give a percentage of total land use for each land-use type within the 500-meter buffer around the well sites. Data indicated that urban settings were the most prominent land use around the High Plains wells (about 63 percent). The study area in east-central Nebraska primarily is agricultural; however, public-supply wells are generally located within city boundaries, and the 500-meter buffers reflect local urban land use. Agricultural land use represented about 25 percent of the land use around each well in the High Plains study area. This agricultural setting includes small

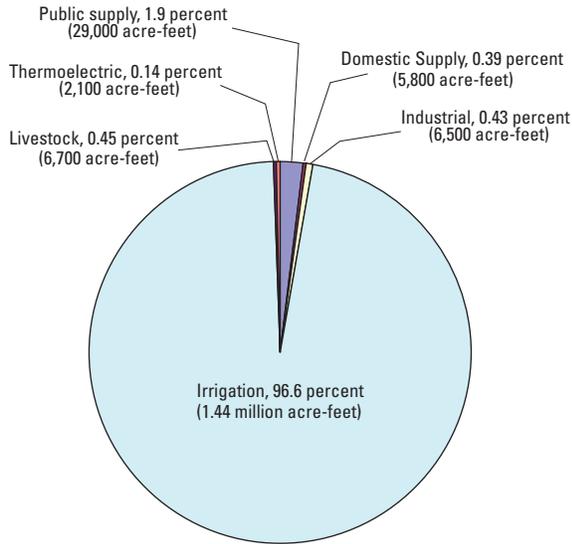
grains, row crops, and hay fields. Rangeland (6 percent) and forested areas (4 percent) were the next most common. The remaining 2 percent of land use was split between open water, bare rock, and wetlands (U.S. Geological Survey, 1992).

In the South Platte study area, land use within the 500-meter buffer around the wells sites predominantly was rangeland, which accounted for 64 percent of the total land-use setting. Urban land use accounted for about 22 percent of the total area within all 500-meter buffers. Agricultural land-use accounted for about 12 percent of the area around the South Platte wells, with the remaining 2 percent represented by open water, forest, and bare rock (U.S. Geological Survey, 1992). The counties in the South Platte study area have been experiencing some of the largest population growth rates in the country with Douglas County having the largest percentage increase in population of any county in the United States between 1990 and 2000 (U.S. Census Bureau, 2001). The land use around each of the sites in the South Platte Basin has been shifting from a historically rangeland setting to a more urbanized setting.

Water-use data were aggregated at the county level to determine usage in the eight Nebraska counties of the High Plains study area (U.S. Geological Survey, 2006). All surface water used in the Nebraska counties was for irrigation, livestock, and mining purposes and accounted for about 6 percent of all water use in 2000. All public and domestic water supplies during 2000 were derived from groundwater sources. Primary use of groundwater in the counties was for irrigation, which accounted for 96.6 percent (1.44 million acre-feet) of all groundwater used (fig. 4A). Public-water supplies accounted for 1.9 percent (29,000 acre-feet) of the total. Domestic water supplies, or wells that supply single family homes or small housing developments, accounted for only 0.39 percent (5,800 acre-feet) of all groundwater use in 2000. Industrial water use accounted for 0.43 percent (6,500 acre-feet) of groundwater use, livestock watering accounted for 0.45 percent (6,700 acre-feet), and thermoelectric uses accounted for 0.14 percent (2,100 acre-feet).

Water-use data for the three South Platte study area counties (Arapahoe, Douglas, and Elbert) also were aggregated for 2000. Surface-water sources accounted for about 75 percent (146,660 acre-feet) of all water use in the three Colorado counties, and surface-water resources were used predominantly (84 percent) for public supply. Irrigation accounted for about 13 percent of surface-water use, and industrial uses accounted for the rest. The remaining 25 percent (48,000 acre feet) of all water used in the South Platte study area was derived from groundwater sources with its uses almost equally distributed between domestic supply (35 percent, or 17,000 acre-feet), public supply (31 percent, or 14,700 acre-feet), and irrigation (30 percent, or 14,400 acre-feet) (fig. 4B). The remaining 4 percent (1,900 acre-feet) of the groundwater used in the South Platte study area was for industrial purposes (U.S. Geological Survey, 2006).

A. High Plains Regional Groundwater



B. South Platte River Basin

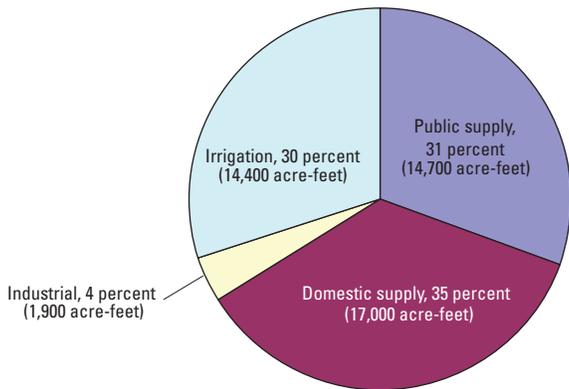


Figure 4. Water use in counties included in the (A) High Plains Regional Groundwater and (B) South Platte River Basin Source Water-Quality Assessment study areas, water year 2000.

Groundwater Hydrology

Groundwater sources for the studies discussed in this report are unconfined (or water table) to confined aquifers that have the potential for contamination from the infiltration of contaminants. The movement of contaminants derived from land-surface activities to the aquifer is increased by unconfined aquifer conditions, relatively shallow water tables, permeable aquifer materials at land surface, and enhanced infiltration from irrigation practices.

Nebraska

The surficial High Plains aquifer in east-central Nebraska mainly consists of unconsolidated Plio-Pleistocene alluvial and glacial deposits of sand, gravel, silt, and clay. Groundwater occurs under unconfined conditions in the glacial sands, although the interbedded deposits can result in locally confined conditions (Landon and Turco, 2007). The saturated thickness of the aquifer ranges from about 50 feet in the northwestern part of the aquifer to about 350 feet near York, Nebraska. The average saturated thickness of the aquifer is about 210 feet.

Well depths for the High Plains study range from about 100 to 400 feet below land surface, with an average depth of 285 feet below land surface. Water levels measured at the time of sampling ranged from 6 to 213 feet below land surface. The distance from the water level to the top of the screened interval ranged from 15 feet to about 200 feet. These minimum and maximum values were extremes in the data set; removing these two extreme values yields an average distance of about 85 feet from the water surface to the top of the screened interval. Regional groundwater flow is from northwest to southeast. Aquifer recharge in this area predominantly is from the infiltration of irrigation return flows but also is supplemented by regional groundwater flow and precipitation (Landon and Turco, 2007).

Colorado

Wells in the South Platte study area are completed in the Dawson and Denver aquifers, which comprise the uppermost units in the Denver Basin aquifer system (Robson and Banta, 1995). The Denver Basin aquifer system is a synclinal structure of sedimentary rocks that dip sharply to the east on the western basin margin. The Dawson aquifer and underlying Denver aquifer are composed of Cretaceous to Tertiary-aged deposits consisting of coarse grained, poorly to well-consolidated sandstones interbedded with conglomerate, siltstone, and shale. The Cretaceous-aged Arapahoe and Laramie-Fox Hills sandstone aquifers underlie the Denver aquifer and outcrop around the edges of the Denver Basin. The Cretaceous Pierre Shale underlies the Laramie-Fox Hills aquifer and is considered the base of the aquifer system (Robson and Banta, 1995). The aquifer system, as a whole, is a primary supplier of groundwater for many areas in the Front Range.

The Dawson aquifer generally is exposed at the land surface in the South Platte study area and reaches depths to 1,100 feet below land surface in the deepest part of the Denver Basin south of the study area (S.S. Paschke, U.S. Geological Survey, written commun., 2008). The Dawson aquifer generally has unconfined conditions in its uppermost parts with the deeper parts of the aquifer displaying confined conditions. The Denver Formation underlies the Dawson aquifer and consists of a 600 to 1,100-foot thick sequence of interbedded sandstone, siltstone, shale, claystone, coal, and volcanic ash (Robson, 1987). The Denver aquifer is composed of

permeable sandstones within the Denver Formation (Robson, 1987). Recharge to the Denver Basin aquifers is derived from infiltration of incident precipitation and irrigation with discharge to evapotranspiration, streams, springs, and wells. Regional groundwater movement in the bedrock aquifers generally is from south to north. Wells included in this study range from 250 to 1,000 feet deep, with an average depth of 640 feet below land surface. Water levels obtained at the time of sampling ranged from 60 to 350 feet below land surface and depth from water surface to the top of the screened interval ranged from 0 to 680 feet, although water-level information was not collected at all sites.

Study Design and Methods

The SWQA study, as developed by the NAWQA program, is intended to provide a better understanding of the prevalence of selected organic compounds in streams and aquifers that serve as primary contributors to municipal water supplies and to characterize the frequency and concentrations in the treated water for the most-frequently detected compounds in source water.

Selection criteria for study areas included in the first year of this nationwide NAWQA effort were based on six factors. The identified study should (1) overlie 1 of the 19 principal aquifers prioritized by NAWQA (Lapham and others, 2005; U.S. Geological Survey, 2003) or an aquifer of regional importance as a drinking-water resource; (2) be nested within the boundaries of existing NAWQA studies slated for periodic resampling as part of the NAWQA water-quality trends network; (3) contain an aquifer that contributes a significant amount of the drinking water to local communities; (4) have existing documentation that the aquifer is vulnerable to anthropogenic and natural contamination; (5) have local water-quality issues related to human activities; and (6) include site-specific criterion in the selection of wells. Wells selected for inclusion in the study should be at least 1 kilometer (3,281 feet) away from any other well in the study, have a large local production rate or population served, and have an unlikely chance to have a direct connection with a surface-water source (G.C. Delzer, U.S. Geological Survey, written comm., 2002).

The High Plains and South Platte SWQA studies started in October 2002 and ended October 2004. Initial project work included study-area characterization and well selection, which required USGS personnel to work closely with local CWS managers. During the first year of the study, the sampling effort was intended to establish the occurrence and distribution of organic compounds in source water from 15 of the highest-producing municipal wells in the aquifer selected for the study.

Sampling sites for the High Plains SWQA study area were within the boundary of the Plio-Pleistocene alluvial and glacial deposits located in east-central Nebraska (fig. 2). Wells

completed in the Plio-Pleistocene alluvial and glacial deposits were selected for the study because this near-surface aquifer is considered extremely vulnerable to contaminants introduced by human activities and also is a primary drinking-water supply for the city of York, Nebraska, and its surrounding communities (Landon and Turco, 2007; Lapham and others, 2005). From the available wells in the targeted study area, the eight wells with the largest annual water production in the York, Nebraska, CWS were chosen for inclusion in this study. The remaining seven wells for the High Plains SWQA study were chosen from the highest-producing wells in nearby communities.

Sites selected for the South Platte study area were all completed in the Dawson or Denver aquifers, the upper most units of the Denver Basin aquifer system. These aquifers were chosen because of their use in numerous CWS, their exposure at the land surface, and, therefore, their potential vulnerability to contaminants introduced at the land surface. The selection of wells for the South Platte study was hampered by the lack of available wells during the study. Although the Dawson aquifer contains numerous CWS wells, these wells commonly are used only seasonally or intermittently as a back-up to the more productive wells in the deeper formations of the Denver Basin aquifer system. With the assistance of local CWS managers, 12 active production wells were identified that met the study criteria.

The design for the second year of the study was to resample a subset of the first-year sample sites where contaminants were detected and focus on the most commonly detected compounds from the first-year nationwide SWQA study results. The second-year study design also included the sampling of finished (treated) water, which represents water supplied to municipal customers that was derived from the parcels of source water sampled before treatment. These finished-water samples were collected after water-quality treatment and may have been subjected to blending of waters from other sources, filtration and chemical treatment to remove particulates or dissolved constituents, and microbial disinfection.

Wells that were sampled in the High Plains and South Platte studies usually had in-line chlorination and water blending occurring just “downstream” from the well head. To sample source water, existing sampling taps were located before any treatment or blending, or new sampling taps were installed by the CWS technicians to facilitate collecting the water sample. All samples were collected following the USGS protocols outlined by the National Field Manual for the Collection of Water-Quality Data (U.S. Geological Survey, variously dated). The VOC samples were collected unfiltered, all other samples were filtered through 0.45-micron filters and are considered dissolved (vs. total) concentrations. Sampling equipment consisted primarily of Teflon tubing with stainless steel fittings and filters.

All samples collected for both studies were analyzed at the USGS National Water Quality Laboratory (NWQL) in Lakewood, Colorado. The various analytical methods for the organic compounds are outlined in Rose and Sandstrom

(2003); Zaugg and others (2002); Sandstrom and others (2001); Furlong and others (2001); and Conner and others (1998). Many of the analytical results for the selected organic compounds were qualified with an estimated (E) designation. These results are reliable detections but are determined to be outside the acceptable laboratory determined calibration curve and have an uncertainty greater than the laboratory average.

Wells resampled in the High Plains study area during the second year of the SWQA were selected on the basis of five criteria: (1) a first-year sample from the well was determined to contain anthropogenic compounds that were detected frequently on a National scale; (2) first-year sample results revealed two or more local wells that had a detection of a single compound not included in the National target list; (3) an individual well had detections of 6 or more of the 289 organic compounds analyzed; (4) a first-year sample had a significant concentration (greater than 10 micrograms per liter ($\mu\text{g/L}$)) of any compound; or (5) there were important local concerns that could be addressed by additional sampling (G.C. Delzer, U.S. Geological Survey, written commun., 2003). Applying these criteria to the 15 High Plains sites identified 2 sites that were selected for resampling during the second year of the SWQA study.

Compound classes analyzed in each water sample included volatile organic compounds (VOC), pesticides and pesticide degradation products, and other organic compounds (OOC) (appendixes 1–3). Because of possible natural sources and suspected sample contamination, the occurrence of carbon disulfide, isophorone, phenol, and only in the case of the South Platte samples, chloroform, could not be related directly to human effects and are not discussed further in this report (Carter and others, 2007). Because of the presence of free chlorine in the finished waters caused by microbial disinfection practices, a dechlorinating reagent (ascorbic acid) and a neutral pH buffer were added to the finished-water samples. A neutral pH buffer was not added to VOC samples because sample preservation protocols for VOC samples include preserving samples with hydrochloric acid, and pH buffers can create interference with the preservation method. Protocols for the collection of the source and finished waters also stipulated that source waters be collected before finished waters and that the sampling team determine, with help from the CWS personnel, the retention time of water passing through the treatment process. This collection process ensured that the best effort possible was made to sample the same parcel of water before and after treatment.

Quality assurance and quality control (QA/QC) of the SWQA sample data for both studies were conducted as part of the larger, NAWQA QA/QC program. The standardization of sampling protocols, sampling equipment, all sample analysis at the NWQL, and consistent quality-assurance sample collection of blanks, replicates, and spikes, allowed for the pooling of quality-assurance data for SWQA studies nationwide. Results from the pesticide analysis indicate there were no reportable systematic sample contaminations

or bias in detected concentrations (Hopple and others, 2005). Analysis of VOC QA/QC data collected for all SWQA studies also indicate concentrations for carbon disulfide were suspect and are not included in this report (Carter and others, 2007). Within the South Platte study, systematic contamination was found in blank samples for chloroform, and results were not included in this report for this study unit. Analysis of the QA/QC data for the OOCs from all SWQA studies show there was some systematic contamination for phenol and that isophorone detections were linked to the preservation methods (Carter and others, 2007).

Regulatory and Non-Regulatory Human-Health Benchmarks

Water-quality results presented in this report are compared to regulatory and non-regulatory health-based water-quality standards to provide a reference for understanding the relative quality of the source waters used for municipal supplies (table 1). Sources of human-health benchmarks include the U.S. Environmental Protection Agency (USEPA) drinking-water standards (U.S. Environmental Protection Agency, 2003, 2004), Nebraska and Colorado State-mandated drinking-water standards (if different from USEPA standards) (Nebraska Health and Human Services, 2005; Colorado Department of Public Health and Environment, 2005), and USGS-developed Health-Based Screening Levels (HBSL) for compounds currently (2004) unregulated on the Federal or State level (Toccalino and others, 2003, 2004). Generally, these Federal and State drinking-water-quality criteria apply only to publicly supplied drinking water at the point of consumption and not to raw source water at the well head. The HBSLs were developed to provide a reference for frequently detected constituents that do not have a regulatory water-quality standard. Comparison of water-quality data to applicable human-health standards, or benchmarks, is useful for local, county, State, and Federal authorities responsible for maintaining drinking-water resources.

The USEPA regulations on drinking-water contaminants most commonly are referred to as “Maximum Contaminant Levels (MCLs)” and represent the maximum allowable concentration of a contaminant allowed in publicly supplied drinking water. These enforceable regulations are applied to the finished waters supplied to the users of the municipal water utility but do not apply to source waters collected before treatment or to self-supplied drinking water from a private domestic source. The MCLs are referenced in this report because they are useful in understanding the relative quality of the source waters before being treated and distributed to the community. Another non-enforceable regulatory benchmark used in this report is the Lifetime Health Advisory (LHA), which is defined as “the concentration of a chemical in drinking water that is not expected to have any adverse noncarcinogenic effects for a lifetime of exposure” (U.S. Environmental

Table 1. Human-health benchmarks used for comparison to source water-quality data for public-supply wells in the High Plains Regional Groundwater study unit and the South Platte River Basin study unit sampled in 2003–2004.

[Federal and State maximum contaminant levels are enforceable standards; the remainder of the listed benchmarks are unenforceable guidelines or public-health goals; USEPA, U.S. Environmental Protection Agency; MCL, Maximum Contaminant Level; OW, Office of Water (USEPA); MCLG, Maximum Contaminant Level Goal; LHA, Lifetime Health Advisory; NHHS, Nebraska Health and Human Services; CDPHE, Colorado Department of Public Health and Environment; HBSL, Health-Based Screening Level; USGS, U.S. Geological Survey; NJDEP, New Jersey Department of Environmental Protection; OHSU, Oregon Health and Science University]

Human-health benchmark	Acronym	Agency	Description	Reference
Maximum Contaminant Level (Federal)	USEPA MCL	USEPA (OW)	The maximum permissible level of a contaminant in water that is delivered to any user of a public-water system. MCLs are set as close to Maximum Contaminant Level Goals (MCLGs) as feasible using the best available treatment technology and taking cost into consideration. The MCLG is the concentration of a contaminant in drinking water at which no known or anticipated adverse health effects occur, and which allows an adequate margin of safety.	(USEPA, 2003, 2004)
Lifetime Health Advisory	LHA	USEPA (OW)	The concentration of a contaminant in drinking water that is not expected to cause any adverse noncarcinogenic effects over a lifetime of exposure (70 years). The LHA is based on exposure of a 70-kilogram (154 pound) adult consuming 2 liters (0.5 gallon) of water per day, and assumes that only part (generally 20 percent) of the total exposure to a contaminant is from drinking water.	(USEPA, 1993, 2004)
Maximum Contaminant Level (State)	Nebraska MCL	NHHS	The MCLs for organic chemical contaminants apply to community and non-transient, non-community water systems.	(NHHS, 2005)
Maximum Contaminant Level (State)	Colorado MCL	CDPHE	The maximum permissible level of a contaminant in water, which is delivered to any user of a public-water system.	(CDPHE, 2005)
Health-Based Screening Level	HBSL	USGS, USEPA, NJDEP, OHSU	Estimates of benchmark concentrations (for noncarcinogens) or concentration ranges (for carcinogens) in water that (a) may be of potential human-health concern; (b) can be used as threshold values against which measured concentrations of contaminants in ambient water samples can be compared; and (c) are consistent with USEPA OW methodologies for setting drinking-water LHA and Risk-Specific Dose values (USEPA, 1988, 1993).	(Toccalino and others, 2003, 2004)

Protection Agency, 2004). Nebraska and Colorado State drinking-water regulations also were assessed where applicable to this study. State drinking-water standards usually are set at the USEPA MCLs; however, individual states may establish drinking-water MCLs at concentrations lower than the USEPA MCL.

Many of the organic compounds sampled for in this study do not have an associated Federal or State drinking-water standard. To assess these unregulated chemicals in a health-based framework, the USGS, in collaboration with the USEPA, New Jersey Department of Environmental Protection, and the Oregon Health and Science University developed benchmarks called the Health-Based Screening Level (HBSL) (Tocallino and others, 2003, 2004). These screening levels are non-enforceable and represent estimates of a benchmark

concentration that can have potential human-health concerns. The HBSLs were developed from the protocols of the USEPA Office of Water determinations of LHA and Risk-Specific Dosage (RSD). Applications of HBSLs are useful in interpreting water-quality data containing non-regulated contaminants and in prioritizing contaminants and assessing the need for further monitoring (Tocallino and others, 2003, 2004).

To quantify potential human-health concerns from the organic data collected and assessed against USEPA, State, or HBSL drinking-water standards or screening levels, a Benchmark Quotient (BQ) was used. The BQ is defined as “the ratio of a contaminant concentration to its corresponding MCL, LHA, or HBSL.” Maximum BQ (BQ_{max}) values represent the maximum measured concentration of a contaminant divided by the corresponding MCL (for regulated compounds) or

HBSL (for unregulated compounds) (Toccalino and others, 2003, 2004). A BQmax value greater than or equal to 1.0 is used to identify compound concentrations of potential human-health concern, and additionally, to determine if further study on a specific compound is needed. A BQmax value greater than or equal to 0.1 is used to identify compounds that may warrant additional monitoring to analyze trends in their occurrence. Additional monitoring may provide an early indication of contaminant levels that approach human-health benchmarks and, consequently, contaminant concentrations of potential human-health concern.

Occurrence of Selected Organic Compounds in Groundwater Used for Public Supply

Nebraska

During the first year of sampling (October 2002 through January 2003), water-quality samples were collected at 15 sites in the High Plains study area (fig. 2). The frequency of detection for all constituents analyzed in the samples is shown in table 2. Of the constituents analyzed, two regulated pesticides and five unregulated pesticides or pesticide degradation products were detected. The most-frequently detected regulated pesticide was atrazine, which had measurable concentrations in 9 of 15 wells (60 percent of the samples). Simazine, another commonly used pesticide, was in 2 of 15 wells (13 percent of the samples) at concentrations estimated below the minimum reporting level (MRL) of 0.005 $\mu\text{g/L}$. Unregulated compounds also were present in the samples. The atrazine degradate, deethylatrazine (DEA or otherwise known as 2-chloro-4-isopropylamino-6-amino-s-triazine or CIAT) was detected in the same 9 of 15 wells as atrazine (60 percent of the samples). The pesticide 2-hydroxyatrazine (2-hydroxy-4-isopropylamino-6-ethylamino-s-triazine or OIET) was detected at concentrations estimated below the MRL of 0.032 $\mu\text{g/L}$ in 3 of 15 wells (20 percent of the samples), and the atrazine degradate deisopropylatrazine (2-chloro-6-ethylamino-4-amino-s-triazine or CEAT) was detected in 2 of 15 wells (13 percent of the samples). Two other unregulated pesticides detected include metolachlor in 2 of 15 wells (13 percent of the samples) and diuron in 1 of 15 wells (7 percent of the samples).

Volatile organic compounds (VOCs) were detected in a few of the source-water samples, and all of the detected VOCs are regulated as drinking-water contaminants. The most-frequently detected VOC was tetrachloroethylene (PCE), a dry cleaning and industrial solvent, which was detected in 4 of the 15 High Plains wells (27 percent of the samples). Chloroform (trichloromethane), a byproduct of water disinfection and a solvent, and the solvent trichloroethylene (TCE) were detected

in 3 of the 15 wells (20 percent of the samples). The most likely source of the chloroform is the chemical reaction of chlorine used to disinfect drinking water with organic matter found in the source-water aquifer (Ivahnenko and Zogorski, 2006). The detection of chloroform in source water indicates finished waters (treated) are recharging the aquifer, possibly through lawn and garden irrigation, recharge of treated wastewaters, or leakage from distribution lines of treated drinking water (Zogorski and others, 2006). Also detected, but at lesser frequencies, were cis-1,2-dichloroethylene in 2 of 15 wells (13 percent of the samples) and 1,2-dichloroethane in 1 of 15 wells (7 percent of the samples). None of the organic compounds detected in the High Plains study had concentrations greater than their regulatory MCL and none had a BQmax greater than the benchmark value of 0.1.

Colorado

During the first year of the South Platte study (March through October 2003), water-quality samples were collected at 12 sites south of Denver, Colorado (fig. 2). Organic compounds were generally not detected in the deep bedrock wells of the South Platte study areas except at two sites. Compounds detected in 1 of the 12 wells (8 percent of the samples) were the regulated pesticides atrazine, its degradation product DEA (unregulated), and picloram, as well as the VOCs PCE, a solvent, methyl-*tert*-butyl ether (MTBE), a gasoline additive, and bromoform, a byproduct of the chlorination of water (table 3). Also detected was the OOC tris(2-butoxyethyl) phosphate, a plasticizer used in rubber products and as a flame retardant. None of the organic compounds detected in the South Platte study had concentrations greater than their regulatory MCL and none had a BQmax greater than the benchmark value of 0.1 (table 3).

Comparison of the Two Source Water-Quality Assessment Studies

Comparison of the SWQA water-quality data from the High Plains and South Platte study areas indicate distinct differences in the type of compounds detected and their frequency of occurrence. A greater number of pesticides were detected in the High Plains study (seven) as compared to the South Platte study (three), and the frequency of detected pesticides was greater in the High Plains study than the South Platte study. The pesticide atrazine and its degradate DEA were detected in both study areas, although the frequency and concentrations were greater in the High Plains study (nine atrazine detections with a mean concentration of 0.03 $\mu\text{g/L}$) than the South Platte study (one atrazine detection with an estimated concentration of 0.003 $\mu\text{g/L}$). The greater number of detected pesticides and the greater frequency of atrazine detections in the High Plains study area than the South Platte study area indicate long-term agricultural land use in the High Plains study area is having a more pronounced effect on the

Table 2. Summary of concentrations, detections frequencies, minimum reporting levels, and maximum contaminant levels for pesticides, volatile organic compounds, and other selected organic compounds detected in 15 public-supply wells in the Plio-Pleistocene aquifer, east-central Nebraska, 2003.

[CASRN, Chemical Abstracts Service Registry Number; MRL, Minimum Reporting Level; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency; MCL, Maximum Contaminant Level; LHA, Lifetime Health Advisory; HBSL, Health-Based Screening Level; BQmax, Benchmark Quotient (maximum detected concentration divided by corresponding MCL); U, unregulated; E, estimated, --, no data; N/A, not available; R, regulated]

Compound	Regulated or unregulated	CASRN ¹	Number of samples	Number of samples with detection	Percentage of samples with detection	MRL (µg/L)	Maximum detected concentration (µg/L)	USEPA MCL ² or LHA ³ (µg/L)	Nebraska MCL ⁴ (µg/L)	HBSL ⁵ (µg/L)	Calculated BQmax
Pesticides											
2-Hydroxyatrazine	U	2163-68-0	15	3	20	0.032	E 0.005	--	--	N/A	--
Atrazine	R	1912-24-9	15	9	60	0.007	0.190	3	3	--	0.06
Deethylatrazine	U	6190-65-4	15	9	60	0.006	E 0.209	--	--	N/A	--
Deisopropylatrazine	U	1007-28-9	15	2	13	0.048	E 0.06	--	--	N/A	--
Diuron	U	330-54-1	15	1	7	0.014	0.04	⁶ 10	--	2–200	0.004
Metolachlor	U	51218-45-2	15	2	13	0.006	E 0.008	⁶ 100	--	100	0.00008
Simazine	R	122-34-9	15	2	13	0.005	E 0.003	4	4	--	0.0008
Volatile organic compounds											
Tetrachloroethylene	R	127-18-4	15	4	27	0.030	0.27	5	5	--	0.05
Trichloroethylene	R	79-01-6	15	3	20	0.038	0.26	5	5	--	0.05
Chloroform	R	67-66-3	15	3	20	0.024	E 0.03	⁷ 80	--	--	0.0004
1,2-dichloroethane	R	107-06-2	15	1	7	0.13	E 0.1	5	5	--	0.02
<i>cis</i> -1,2-dichloroethylene	R	156-59-2	15	2	13	0.024	0.18	70	70	--	0.003
Other selected organic compounds											
Isophorone	U	78-59-1	15	1	7	0.5	E 0.3	⁶ 100	--	--	0.003

¹ This report contains CAS Registry Numbers®, which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS client ServicesSM.

² U.S. Environmental Protection Agency, 2003, 2004.

³ U.S. Environmental Protection Agency, 1993, 2004.

⁴ Nebraska Health and Human Services, 2005.

⁵ Toccalino and others, 2003, 2004.

⁶ Lifetime Health Advisory.

⁷ The MCL is for sum of all trihalomethanes (chloroform, bromodichloromethane, dibromochloromethane, and bromoform).

Table 3. Summary of concentrations, detections frequencies, minimum reporting levels, and maximum contaminant levels for pesticides, volatile organic compounds, and other selected organic compounds detected in 12 public-supply wells in the Dawson and Denver aquifers near Denver, Colorado, 2003.

[CASRN, Chemical Abstracts Service Registry Number; MRL, Minimum Reporting Level; µg/L, micrograms per liter; USEPA, U.S. Environmental Protection Agency; MCL, Maximum Contaminant Level; LHA, Lifetime Health Advisory; HBSL, Health-Based Screening Level; BQmax, Benchmark Quotient (maximum detected concentration divided by corresponding MCL); R, regulated; E, estimated, --, no data; U, unregulated; N/A, not available]

Compound	Regulated or unregulated	CASRN ¹	Number of samples	Number of samples with detection	Percentage of samples with detection	MRL (µg/L)	Maximum detected concentration (µg/L)	USEPA MCL ² or LHA ³ (µg/L)	Colorado MCL ⁴ (µg/L)	HBSL ⁵ (µg/L)	Calculated BQmax
Pesticides											
Atrazine	R	1912-24-9	12	1	8	0.007	E 0.003	3	3	--	0.001
Picloram	R	1918-02-1	12	1	8	0.032	0.07	500	500	--	0.0001
Deethylatrazine	U	6190-65-4	12	1	8	0.006	E 0.003	--	--	N/A	--
Volatile organic compounds											
Tetrachloroethylene	R	127-18-4	12	1	8	0.03	E 0.02	5	5	--	0.004
Methyl <i>tert</i> -butyl ether	R	1634-04-4	12	1	8	0.1	1.2	⁶ 20–40	--	--	0.06–0.03
Bromoform	R	75-25-2	12	1	8	0.1	E 0.9	80	--	--	0.01
Other anthropogenic organic compounds											
Tris(2-butoxyethyl) phosphate	U	78-51-3	12	1	8	0.5	E 0.1	--	--	N/A	--

¹ This report contains CAS Registry Numbers®, which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS client ServicesSM.

² U.S. Environmental Protection Agency, 2003, 2004.

³ U.S. Environmental Protection Agency, 1993, 2004.

⁴ Colorado Department of Public Health and Environment, 2005.

⁵ Toccalino and others, 2003, 2004.

⁶ Taste and odor threshold.

water quality than in the more recently urbanized South Platte study area.

The frequency and concentration of VOCs also were different between the two studies. In the High Plains study, five VOCs were detected in the first-year source-water samples (table 2), and three VOCs were detected in the South Platte first-year source-water samples (table 3). Only one compound, PCE, was detected in wells from both studies. The detection of a VOC compound in both study areas indicate urban land use in both areas is affecting water quality. The greater detection frequencies and maximum concentrations of VOCs in the High Plains study area likely reflect the shallow depths to water and more permeable alluvial deposits in the High Plains study area, which allow more rapid transport of compounds in urban-affected recharge as compared to the South Platte study area.

Source and Finished Waters

The second phase of the SWQA study was to resample wells from phase one that had significant contaminant detections and compare these data to samples collected from finished waters derived from the raw-water sources. Second-year sampling was conducted only in the High Plains study area. No second-year samples were collected for the South Platte study because of the relatively low number of detections and concentrations of organics, and the organics detected were not analytes of National or local interest.

Two of the original 15 sampling sites in the High Plains study area were selected to be sampled in the second year based on the total number of contaminant detections, detections of compounds of a National interest, and the relative large concentrations present in the first-year samples. These two new sampling sites, hereinafter referred to as “sites A and B,” represent finished (or treated) waters whose origins were the source-water wells tested in the first year. To determine the frequency and concentrations of contaminants in the finished waters, source-water samples were again collected and, depending on the residence time of the source water in the water-treatment process, a finished-water sample was collected at the estimated time that the same parcel of source water was exiting the treatment facility for distribution to users. Treatment processes at both sites included blending of source waters, in-line chlorination/fluoridation, aeration, and filtration. Site A also included reverse osmosis in its treatment processes.

Results from the second-year SWQA study in the High Plains study area are given in table 4. Although results between the first and second year of source-water sampling at site A indicate variability in the measured constituents and concentrations, the results for site B indicate no change in pesticide concentrations. In source waters from sites A and B, the pesticide atrazine and its degradate DEA (deethylatrazine) were detected in samples from both sampling events. Atrazine and DEA also were detected in the associated finished waters. Atrazine and DEA concentrations were less in the finished

waters than the source waters at site A, whereas pesticide concentrations measured at site B were similar between source and finished water. BQmax for all the samples were well below 0.1 indicating that atrazine is not a high-priority compound at the time of sampling (2004).

Data from the second-year sampling of the source and finished water at site A indicate additional compounds were present in the finished waters (chloroform, bromodichloromethane, dibromodichloromethane, metsulfuron-methyl, m/p xylene, total o-xylene, chlorobenzene, and ethylbenzene) that were not detected in the source waters. These compounds are not likely byproducts of any water-treatment process, but possibly an artifact of source-water blending during the treatment process. The multiple source waters used in the blending process were not sampled for this study.

Common to finished-water samples from sites A and B was the detection of chlorinated organic compounds not detected in source-water samples. The compounds detected in the finished waters include chloroform, bromodichloromethane, dibromochloromethane and bromoform, which are more commonly known as disinfection byproducts (DBPs) or trihalomethanes (THMs). Although these compounds may be present in the other source waters blended with the site A and B water during treatment, it is more likely that these compounds were produced by chlorination of the water for microbial disinfection during the water-treatment process. These THMs most commonly are regulated as the sum of their concentrations and termed total trihalomethanes, or TTHMs. These compounds are a common byproduct of the disinfection process in waters that contain dissolved organic carbon (DOC) (Ivahnenco and Zogorski, 2006). Although samples were not analyzed for DOC by this study, the detection of THMs in the finished waters indicates the source water has some level of DOC that is being oxidized by the addition of chlorine during the treatment processes at sites A and B. TTHM concentrations at site A, and the resulting BQmax value of the TTHMs, are at levels below regulatory concern. At site B, the TTHMs BQmax value of 0.18 is above the concern threshold of 0.1 and is an indication that the TTHMs in the finished waters at site B are at concentrations that warrant closer attention and further monitoring. None of the finished-water samples contained any measured compound concentration above applicable water-quality standards.

Comparison to Other Community Water Systems Well Data

The completion of all SWQA studies conducted by the NAWQA program is still in its final stages; however, data from other NAWQA study units are available for comparison with the data collected for these studies. Data from the SWQA sampling of 15 public-supply wells in the Nevada Basin and Range study unit (Stockton and others, 2003), as well as the sampling of 15 wells in a similar study in the Great Salt Lake NAWQA

Table 4. Comparison of detected contaminants from source and finished waters from selected public-supply wells in the Plio-Pleistocene aquifer, east-central Nebraska, 2003 and 2004.[$\mu\text{g/L}$, micrograms per liter; BQmax, Benchmark Quotient (maximum detected concentration divided by corresponding Maximum Contaminant Level); --, no data; E, estimated; ND, not detected]

Well	Compounds	Source water 2003		Source water 2004		Finished water 2004	
		Concentration $\mu\text{g/L}$	BQmax	Concentration $\mu\text{g/L}$	BQmax	Concentration $\mu\text{g/L}$	BQmax
High Plains Regional Groundwater study site A	Atrazine	0.129	0.04	0.083	0.03	0.018	0.006
	Deethylatrazine	0.209	--	E 0.118	--	E 0.026	--
	Deisopropylatrazine	E 0.04	--	E 0.01	--	E 0.01	--
	Chloroform	ND	--	E 0.02	0.0003	¹ 0.28	¹ 0.03
	Bromodichloromethane	ND	--	ND	--	¹ 0.73	¹ 0.03
	Dibromochloromethane	ND	--	ND	--	¹ 1.20	¹ 0.03
	Bromoform	ND	--	ND	--	E ¹ 0.4	¹ 0.03
	Metsulfuron-methyl	ND	--	ND	--	E 0.01	--
	<i>m/p</i> Xylene	ND	--	ND	--	E 0.05	0.000005
	Total <i>o</i> -xylene	ND	--	ND	--	E 0.02	0.000002
	Chlorobenzene	ND	--	ND	--	E 0.01	0.0001
	Ethylbenzene	ND	--	ND	--	E 0.02	0.00003
High Plains Regional Groundwater study site B	Atrazine	0.028	0.009	0.034	0.01	0.039	0.01
	Deethylatrazine	0.013	--	E 0.012	--	E 0.013	--
	2-Hydroxyatrazine	E 0.004	--	ND	--	ND	--
	Metolachlor	E 0.004	0.00004	ND	--	ND	--
	Simazine	E 0.002	0.0005	ND	--	ND	--
	Chloroform	ND	--	ND	--	E ¹ 0.43	¹ 0.18
	Bromoform	ND	--	ND	--	E ¹ 6.7	¹ 0.18
	Bromodichloromethane	ND	--	ND	--	¹ 1.98	¹ 0.18
Dibromochloromethane	ND	--	ND	--	¹ 4.9	¹ 0.18	

¹ The Maximum Contaminant Level for total trihalomethanes is for the sum of the concentrations of chloroform, bromodichloromethane, dibromochloromethane, and bromoform; therefore, the BQmax is the sum of the concentrations divided by the 80 $\mu\text{g/L}$ Maximum Contaminant Level.

study unit (Thiros and Manning, 2004), are available for comparison. Comparing data collected in different study units allows for the regional synthesis of the data and helps place the SWQA data from the High Plains and South Platte study areas into a regional context. Although data comparisons from these areas are limited because of differences in climate, hydrogeology, land use, and water use, a general comparison can be made based on the similarities of relatively young aquifers, study design, and protocols. A comparison of the four commonly detected contaminants in source waters— atrazine, DEA, chloroform, and PCE—from these four studies is shown in table 5.

The detection frequency of atrazine, DEA, chloroform, and PCE and their concentrations in source water sampled for the Nevada Basin and Range, Great Salt Lake Basins, High Plains, and South Platte study areas varied by study and are best attributed to differences in land-use practices and hydrogeologic setting. Results from the Great Salt Lake Basin and Nevada Basin and Range study units show frequency of detections and concentrations for a majority of the compounds were

intermediate between those in the High Plains and South Platte Studies. Of the four study areas, the High Plains study has the most extensive agricultural land use overlying an unconfined shallow aquifer (Landon and Turco, 2007) and consequently has the highest detection frequency and concentrations of the pesticide atrazine and its degradate DEA. The Nevada Basin and Range and Great Salt Lake Basins study areas also have a history of agricultural practices, but these areas have seen recent (2004) transitions from agricultural to urban land use (Bevans and others, 1998; Thiros and Manning, 2004). The South Platte study area had the lowest overall detection frequency and concentrations of the selected compounds, most likely attributed to the recent (2004) urbanization of historically rangeland areas in Colorado overlying unconfined to confined deep bedrock aquifers. Samples from all study areas except the South Platte contained measurable concentrations of chloroform, with unusually high detection frequencies and concentrations in the Great Salt Lake Basins study, attributed to the injection of chlorinated water into the aquifer during

Table 5. Comparison of selected organic compounds in source-water samples collected in the High Plains Regional Groundwater, the South Platte River Basin, the Nevada Basin and Range, and the Great Salt Lake Basins study units of the National Water-Quality Assessment Program.

[N, number of samples; µg/L, micrograms per liter; BQmax, Benchmark Quotient (maximum detected concentration divided by corresponding maximum contaminant level); E, estimated; --, no data]

Compounds	High Plains Regional Groundwater N=15			South Platte River Basin N=12			Nevada Basin and Range N=15			Greater Salt Lake Basins N=31		
	Number of detections	Maximum concentration (µg/L)	BQmax	Number of detections	Maximum concentration (µg/L)	BQmax	Number of detections	Maximum concentration (µg/L)	BQmax	Number of detections	Maximum concentration (µg/L)	BQmax
Atrazine	9	0.190	0.06	1	E 0.003	0.001	3	0.01	0.003	7	0.034	0.01
Deethylatrazine	9	E 0.209	--	1	E 0.003	--	4	E 0.04	--	10	E 0.07	--
Tetrachloroethylene	4	0.27	0.05	1	E 0.02	0.004	2	0.4	0.08	3	1.0	0.2
Chloroform	3	E 0.03	0.0004	--	--	--	5	0.2	0.003	17	19.7	0.2

certain periods of the year (Thiros and Manning, 2004). The VOC PCE was detected at about the same frequency in samples from all four study units, with the exception of the South Platte study, which had the least number of detections and the lowest concentrations. This may be attributed to the more recent (1994–2004) change toward urbanization in the South Platte study area, the affects of which may not be apparent for many years (if at all) because of the slow migration of shallow water to the deep aquifer. It should be noted that the BQmax for chloroform and PCE in the Great Salt Lake Basins study were greater than the benchmark 0.1 threshold indicating future monitoring of these two compounds may be warranted.

Summary

The National Water-Quality Assessment Program of the U.S. Geological Survey has an ongoing Source Water-Quality Assessment (SWQA) program designed to characterize the quality of water in aquifers used as a primary drinking-water sources for municipal suppliers in major metropolitan areas. Groundwater SWQA studies focus on municipal supply systems that produce water from large-scale regional aquifers that are considered vulnerable to contamination from anthropogenic sources.

Source Water-Quality Assessment studies were conducted in the High Plains (east-central Nebraska region) and South Platte (south Denver, Colorado, metropolitan region) study units of the National Water-Quality Assessment Program during 2002–2004. The first year of this study included the sampling of source waters, which in the context of this report are defined as “the raw water pumped directly from aquifers before any water treatment.” In the second year of the study, source water from the first-year wells was resampled where contaminant detections occurred most frequently, and samples were collected from the finished waters derived from those same sites. Finished waters, in the context of this report, are defined as “waters that have passed through the water-quality treatment process and represent the post-treatment source water.” The goal of these SWQA studies was to determine the occurrence and distribution of selected organic compounds in the source and finished waters distributed as public drinking-water supply in selected areas.

The High Plains study area is in east-central Nebraska in an area of Plio-Pleistocene alluvial and glacial deposits. The South Platte study area overlies the Dawson and Denver aquifers of the Denver Basin aquifer system and is on the southern edge of the Denver metropolitan area. Data from these two studies were evaluated individually and with data from other NAWQA study units to better understand the effects land use and hydrogeologic settings have on groundwater quality.

Results from the source-water-quality sampling were compared to Federal and State water-quality standards or screening levels to present the results in a health-based framework. Sources of water-quality standards and screening levels

include the U.S. Environmental Protection Agency Maximum Contaminant Levels (MCL) and Lifetime Health Advisories (LHA), State Maximum Contaminant Levels, and U.S. Geological Survey derived Health-Based Screening Levels (HBSL).

Of the 15 sample sites in the High Plains study area, 13 organic compounds were detected at varying frequencies in the first year of the study. These organic compounds included pesticides, volatile organic compounds (VOC), and other organic compounds of concern. The most-frequently detected compounds were the pesticide atrazine and its degradate deethylatrazine (detected in 9 of the 15 wells), although concentrations measured in samples were well below MCL standards. The second most frequently detected organic compound was tetrachloroethylene, detected in 4 of the 15 wells, followed by chloroform, trichloroethylene, and 2-hydroxyatrazine (2-hydroxy-4-isopropylamino-6-ethylamino-s-triazine, or OIET), present in 3 of the 15 wells. The pesticide compounds deisopropylatrazine (2-chloro-6-ethylamino-4-amino-s-triazine, or CEAT), metolachlor, and simazine and the VOC cis-1,2-dichloroethylene were detected in 2 of the 15 wells, and the compounds diuron and 1,2-dichloroethane were detected in only 1 of the 15 wells during the first-year sampling. Volatile organic compounds detected in the first year of the study included tetrachloroethylene (PCE), chloroform, trichloroethylene, cis-1,2-dichloroethylene, and 1,2-dichloroethane. Most detections of these compounds were at or near the minimum reporting levels, and none were greater than their regulatory maximum contaminant level.

Source-water collected for the South Platte study had 7 different organic compounds detected in the 2 of the 12 groundwater samples collected. Compounds detected only once in the 12 samples include the pesticides atrazine, its degradate deethylatrazine, picloram, PCE, methyl-*tert*-butyl ether (MTBE), bromoform, and tris(2-butoxyethyl)phosphate. Most detections of these compounds were at or near the minimum reporting levels, and none were greater than their regulatory maximum contaminant level.

Comparison of the water-quality data from the High Plains and South Platte study areas indicate distinct differences in the type of compounds detected and their frequency of occurrence. A greater number of pesticides were detected in the High Plains study (seven) as compared to the South Platte study (three) and the frequency of detected pesticides indicate long-term agricultural land use in the High Plains study area is having a more pronounced effect on the water quality than found in the more recently urbanized South Platte study area. The frequency and concentration of VOCs were different between the two studies. More VOCs were detected in the High Plains study area than in the South Platte first-year source-water samples. The detections of VOC compounds in both study areas indicate urban land use in both areas is affecting water quality. The greater detection frequencies and maximum concentrations of VOCs in the High Plains study area likely are a reflection of the shallow depths to water and more permeable alluvial deposits in the High Plains study area,

which allow more rapid transport of compounds in urban-affected recharge as compared to the South Platte study area.

Second-year sampling, which included the addition of paired source- and finished-water samples, was completed at two sites in the Nebraska study. Source-water samples from the second-year sampling had detections of atrazine and deethylatrazine; at one site deisopropylatrazine and chloroform also were detected. The finished-water samples, which represent the source water after blending with water from other wells and treatment, indicated a decrease in the concentrations of the pesticides at one site, whereas concentrations remained nearly constant at a second site. The trihalomethanes (THMs or disinfection byproducts), chloroform, bromoform, bromodichloromethane, and dibromochloromethane were detected in all finished-water samples and are a result of the chlorine added during treatment reacting with organics in the source waters. Finished waters at one site also contained concentrations of organic compounds not present in the source-water sample, indicating that other wells may be contributing compounds to the finished waters. Results show that all detected organic compounds were well below any applicable standard.

The data collected for this study also were compared to data collected in two similar study areas in Nevada and Utah in order to place the results in a more regional context. Results from the Great Salt Lake Basin and Nevada Basin and Range study units show that frequency of detections and concentrations for a majority of the compounds were intermediate between those in the High Plains and South Platte studies. Although data comparisons from these areas are limited because of difference in climate, hydrogeology, land use, and water use, a general comparison can be made based on the similarities of relatively young aquifers, study design, and protocols. Of all the study areas, the most extensive irrigated agriculture occurs in the High Plains study area, which corresponds with the largest concentrations and frequency of detections of pesticides. The study areas in the Nevada Basin and Range and Great Salt Lake Basins study units have a history of agricultural land uses that are transitioning to a more urban land use. The lowest frequency of organic compound detections and concentrations occurred in the South Platte study area, which is going through a more recent (1994–2004) change from rangeland to urban land use. The effects of the conversion to urban land use may not be apparent for many years (if at all) because of the slow migration of shallow water to the deep aquifer in the South Platte study area.

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Appendixes 1–3

Appendix 1. Volatile organic compounds analyzed in the Source Water-Quality Assessment studies in the South Platte River Basin and High Plains Regional Groundwater National Water-Quality Assessment study areas during 2003–2004.

[CASR, Chemical Abstracts Service Registry Number; µg/L, micrograms per liter; shading represents compound detected in the study; **Bold type** under compound heading indicates unregulated compound, for which no Federal and (or) State drinking-water standards have been established; regulated is a compound for which Federal and (or) State drinking-water standards have been established]

Regulated or unregulated compound	CASRN ¹	Minimum reporting level µg/L	Remark
1,2,3,4-Tetramethylbenzene	488-23-3	0.14	
1,2,3,5-Tetramethylbenzene	527-53-7	0.14	
2-Butanone	78-93-3	2	
<i>trans</i> -1,4-Dichloro-2-butene	110-57-6	0.7	
2-Hexanone	591-78-6	0.4	
4-Methyl-2-pentanone	108-10-1	0.37	
Acetone	67-64-1	6	
Acrylonitrile	107-13-1	0.8	
Benzene	71-43-2	0.021	
1,2,3-Trichlorobenzene	87-61-6	0.18	
1,2,3-Trimethylbenzene	526-73-8	0.06	
1,2,4-Trichlorobenzene	120-82-1	0.12	
Bromobenzene	108-86-1	0.028	
Chlorobenzene	108-90-7	0.028	Used as a solvent for some pesticide formulations, to degrease automobile parts, and as a chemical intermediate to make several other chemicals.
Ethylbenzene	100-41-4	0.03	Used primarily to make another chemical, styrene. Other uses include as a solvent, in fuels, and to make other chemicals.
1,3-Dichlorobenzene	541-73-1	0.03	
Butylbenzene	104-51-8	0.12	
<i>n</i> -Propylbenzene	103-65-1	0.042	
1,2-Dichlorobenzene	95-50-1	0.048	
1,4-Dichlorobenzene	106-46-7	0.034	
<i>sec</i> -Butylbenzene	135-98-8	0.06	
<i>tert</i> -Butylbenzene	98-06-6	0.06	
Bromoethene	593-60-2	0.1	
Bromoform	75-25-2	0.1	Byproduct when chlorine is added to water-supply systems.
Hexachlorobutadiene	87-68-3	0.14	
Carbon disulfide	75-15-0	0.038	Occurs naturally; manufactured chemical is used as a solvent in industrial processes.
Tetrachloromethane	56-23-5	0.06	
Chloroform	67-66-3	0.024	Also known as trichloromethane, byproduct when chlorine is added to water-supply systems; used as a solvent.
Isopropylbenzene	98-82-8	0.038	
1,1,1,2-Tetrachloroethane	630-20-6	0.03	
1,1,1-Trichloroethane	71-55-6	0.032	
1,1,2-Trichlorotrifluoroethane	76-13-1	0.038	
1,2-Dibromoethane	106-93-4	0.036	
1,2-Dichloroethane	107-06-2	0.13	The most common use of 1,2-dichloroethane is in the production of vinyl chloride which is used to make a variety of plastic and vinyl products including polyvinyl chloride (PVC) pipes. It is also used as a solvent and is added to leaded gasoline to remove lead.
Hexachloroethane	67-72-1	0.14	
1,1,2,2-Tetrachloroethane	79-34-5	0.08	
Chloroethane	75-00-3	0.12	

Appendix 1. Volatile organic compounds analyzed in the Source Water-Quality Assessment studies in the South Platte River Basin and High Plains Regional Groundwater National Water-Quality Assessment study areas during 2003–2004.—Continued

[CASR, Chemical Abstracts Service Registry Number; µg/L, micrograms per liter; shading represents compound detected in the study; **Bold type** under compound heading indicates unregulated compound, for which no Federal and (or) State drinking-water standards have been established; regulated is a compound for which Federal and (or) State drinking-water standards have been established]

Regulated or unregulated compound	CASRN ¹	Minimum reporting level µg/L	Remark
Diethyl ether	60-29-7	0.08	
Ethyl <i>tert</i> -butyl ether	637-92-3	0.03	
<i>cis</i>-1,2-Dichloroethylene	156-59-2	0.024	Used as a solvent for waxes and resins; used as a refrigerant.
Tetrachloroethylene	127-18-4	0.03	Also known as tetrachloroethene and PCE, primarily used as dry cleaning agent.
<i>trans</i> -1,2-Dichloroethylene	156-60-5	0.032	
Trichloroethylene	79-01-6	0.038	Also known as trichloroethane and TCE, solvent.
1,1-Dichloroethane	75-34-3	0.035	
Tetrahydrofuran	109-99-9	1	
Diisopropyl ether	108-20-3	0.1	
<i>m</i>- and <i>p</i>-Xylene	m=108-38- p=106-42-3	0.06	Occurs naturally in petroleum; manufactured chemical is used in chemical processes and pesticides.
1,3,5-Trimethylbenzene	108-67-8	0.044	
Ethyl methacrylate	97-63-2	0.18	
Methyl methacrylate	80-62-6	0.2	
Methyl acrylonitrile	126-98-7	0.4	
Bromochloromethane	74-97-5	0.12	
Bromodichloromethane	75-27-4	0.028	Also known as dichlorobromomethane; byproduct when chlorine is added to water-supply systems.
Dibromochloromethane	124-48-1	0.1	Also known as chlorodibromomethane; byproduct when chlorine is added to water-supply systems.
Dichlorodifluoromethane	75-71-8	0.18	
Trichlorofluoromethane	75-69-4	0.08	
Methyl acrylate	96-33-3	1	
Bromomethane	74-83-9	0.26	
Chloromethane	74-87-3	0.17	
Methyl iodide	74-88-4	0.5	
Methyl-<i>tert</i>-butyl ether	1634-04-4	0.1	Gasoline additive.
Dibromomethane	74-95-3	0.05	
Dichloromethane	75-09-2	0.06	
Naphthalene	91-20-3	0.52	
<i>o</i>-Xylene	95-47-6	0.038	Used in the production of plastics, dyes, and insecticides.
4-Isopropyl-1-methylbenzene	99-87-6	0.08	
1,2,3-Trichloropropane	96-18-4	0.18	
1,3-Dichloropropane	142-28-9	0.06	
2,2-Dichloropropane	594-20-7	0.05	
1,2-Dibromo-3-chloropropane	96-12-8	0.51	
1,1-Dichloropropene	563-58-6	0.026	
3-Chloropropene	107-05-1	0.5	
<i>cis</i> -1,3-Dichloropropene	10061-01-5	0.05	
<i>trans</i> -1,3-Dichloropropene	10061-02-6	0.09	
1,2-Dichloropropane	78-87-5	0.029	
1,2,4-Trimethylbenzene	95-63-6	0.056	
<i>tert</i> -Pentyl methyl ether	994-05-8	0.04	

Appendix 1. Volatile organic compounds analyzed in the Source Water-Quality Assessment studies in the South Platte River Basin and High Plains Regional Groundwater National Water-Quality Assessment study areas during 2003–2004.—Continued

[CASR, Chemical Abstracts Service Registry Number; µg/L, micrograms per liter; shading represents compound detected in the study; **Bold type** under compound heading indicates unregulated compound, for which no Federal and (or) State drinking-water standards have been established; regulated is a compound for which Federal and (or) State drinking-water standards have been established]

Regulated or unregulated compound	CASRN¹	Minimum reporting level µg/L	Remark
Toluene	108-88-3	0.02	
2-Chlorotoluene	95-49-8	0.04	
<i>o</i> -Ethyl toluene	611-14-3	0.06	
4-Chlorotoluene	106-43-4	0.05	
Vinyl chloride	75-01-4	0.08	
1,1,2-Trichloroethane	79-00-5	0.04	
1,1-Dichloroethylene	75-35-4	0.024	

¹ This report contains CAS Registry Numbers[®], which is a Registered Trademark of the American Chemical Society. CAS recommends the verification of the CASRNs through CAS client ServicesSM.

Appendix 2. Pesticide compounds analyzed in the Source Water-Quality Assessment studies in the South Platte River Basin and High Plains Regional Groundwater National Water-Quality Assessment study areas during 2003–2004.

[CASR, Chemical Abstracts Service Registry Number; µg/L, micrograms per liter; shading represents compound detected in the study; **Bold type** under compound heading indicates unregulated compound, for which no Federal and (or) State drinking-water standards have been established; regulated is a compound for which Federal and (or) State drinking-water standards have been established]

Regulated or unregulated compound	CASRN ¹	Minimum reporting level (µg/L)	Remark
2,4-D	94-75-7	0.038	
2,4-D methyl ester	1928-38-7	0.016	
2,4-DB	94-82-6	0.02	
2-Hydroxy-4-isopropylamino-6-ethylamino-s-triazine (OIET)	2163-68-0	0.032	Breakdown product of atrazine; also referred to as 2-Hydroxyatrazine.
3(4-Chlorophenyl)-1-methyl urea	5352-88-5	0.036	
3-Ketocarbofuran	16709-30-1	0.02	
Acifluorfen	50594-66-6	0.028	
Aldicarb	116-06-3	0.04	
Aldicarb sulfone	1646-88-4	0.018	
Aldicarb sulfoxide	1646-87-3	0.022	
Chloramben, methyl ester	7286-84-2	0.024	
Atrazine	1912-24-9	0.007	Herbicide.
Bendiocarb	22781-23-3	0.02	
Benomyl	17804-35-2	0.022	
Bensulfuron-methyl	83055-99-6	0.018	
Bentazon	25057-89-0	0.012	
Bromacil	314-40-9	0.018	
Bromoxynil	1689-84-5	0.028	
Carbaryl	63-25-2	0.018	
Carbofuran	1563-66-2	0.016	
3-Hydroxycarbofuran	16655-82-6	0.008	
Chlorimuron-ethyl	90982-32-4	0.032	
Chlorothalonil	1897-45-6	0.035	
Clopyralid	1702-17-6	0.024	
Cycloate	1134-23-2	0.014	
Dacthal monoacid	887-54-7	0.028	
2-Chloro-4-isopropylamino-6-amino-s-triazine (CIAT)	6190-65-4	0.006	Breakdown product of atrazine; also referred to as Deethylatrazine.
Chlordiamino-s-triazine (CAAT)	3397-62-4	0.022	
2-Chloro-6-ethylamino-4-amino-s-triazine (CEAT)	1007-28-9	0.08	Breakdown product of atrazine; also referred to as Deisopropylatrazine.
Dicamba	1918-00-9	0.036	
Dichlorprop	120-36-5	0.028	
Dinoseb	88-85-7	0.038	
Diphenamid	957-51-7	0.01	
Diuron	330-54-1	0.014	Herbicide.
Fenuron	101-42-8	0.018	
Flumetsulam	98967-40-9	0.04	
Fluometuron	2164-17-2	0.016	
Imazaquin	81335-37-7	0.036	
Imazethapyr	81335-77-5	0.038	
Imidacloprid	138261-41-3	0.02	
Linuron	330-55-2	0.014	

Appendix 2. Pesticide compounds analyzed in the Source Water-Quality Assessment studies in the South Platte River Basin and High Plains Regional Groundwater National Water-Quality Assessment study areas during 2003–2004.—Continued

[CASR, Chemical Abstracts Service Registry Number; µg/L, micrograms per liter; shading represents compound detected in the study; **Bold type** under compound heading indicates unregulated compound, for which no Federal and (or) State drinking-water standards have been established; regulated is a compound for which Federal and (or) State drinking-water standards have been established]

Regulated or unregulated compound	CASRN ¹	Minimum reporting level (µg/L)	Remark
MCPA	94-74-6	0.03	
MCPB	94-81-5	0.01	
Metalaxyl	57837-19-1	0.0051	
Methiocarb	2032-65-7	0.01	
Methomyl	16752-77-5	0.02	
Metsulfuron-methyl	74223-64-6	0.025	
Neburon	555-37-3	0.012	
Nicosulfuron	111991-09-4	0.04	
Norflurazon	27314-13-2	0.02	
Oryzalin	19044-88-3	0.012	
Oxamyl	23135-22-0	0.03	
Picloram	2/1/1918	0.032	Herbicide.
Prometon	1610-18-0	0.01	
Propham	122-42-9	0.03	
Propiconazole	60207-90-1	0.01	
Propoxur	114-26-1	0.008	
Siduron	1982-49-6	0.02	
Simazine	122-34-9	0.005	Herbicide.
Sulfometuron-methyl	74222-97-2	0.038	
Tebuthiuron	34014-18-1	0.016	
Terbacil	5902-51-2	0.016	
Tribenuron-methyl	101200-48-0	0.0088	
Tricopyr	55335-06-3	0.026	
1-Naphthol	90-15-3	0.0882	
2-Chloro-2,6-diethylacetanilide	6967-29-9	0.005	
2-Ethyl-6-methylaniline	24549-06-2	0.0045	
3,4-Dichloroaniline	95-76-1	0.0045	
4-Chloro-2-methylphenol	1570-64-5	0.0057	
Acetochlor	34256-82-1	0.006	
Alachlor	15972-60-8	0.005	
2,6-Diethylaniline	579-66-8	0.006	
Azinphos-methyl	86-50-0	0.05	
Azinphos-methyl-oxon	961-22-8	0.07	
Benfluralin	1861-40-1	0.01	
Chlorpyrifos	2921-88-2	0.005	
Chlorpyrifos, oxygen analog	5598-15-2	0.0562	
<i>cis</i> -Permethrin	54774-45-7	0.006	
Cyfluthrin	68359-37-5	0.008	
Cypermethrin	52315-07-8	0.0086	
Dacthal	1861-32-1	0.003	
Diazinon	333-41-5	0.005	
Diazinon, oxygen analog	962-58-3	0.006	
Dichlorvos	62-73-7	0.0118	
Dicrotophos	141-66-2	0.0843	

Appendix 2. Pesticide compounds analyzed in the Source Water-Quality Assessment studies in the South Platte River Basin and High Plains Regional Groundwater National Water-Quality Assessment study areas during 2003–2004.—Continued

[CASR, Chemical Abstracts Service Registry Number; µg/L, micrograms per liter; shading represents compound detected in the study; **Bold type** under compound heading indicates unregulated compound, for which no Federal and (or) State drinking-water standards have been established; regulated is a compound for which Federal and (or) State drinking-water standards have been established]

Regulated or unregulated compound	CASRN¹	Minimum reporting level (µg/L)	Remark
Diieldrin	60-57-1	0.009	
Dimethoate	60-51-5	0.0061	
Ethion	563-12-2	0.004	
Ethion monooxon	17356-42-2	0.002	
Fenamiphos	22224-92-6	0.029	
Fenamiphos sulfone	31972-44-8	0.0491	
Fenamiphos sulfoxide	31972-43-7	0.0387	
Desulfinylfipronil amide		0.029	
Fipronil sulfide	120067-83-6	0.013	
Fipronil sulfone	120068-36-2	0.024	
Desulfinylfipronil		0.012	
Fipronil	120068-37-3	0.016	
Fonofos	944-22-9	0.003	
Fonofos, oxygen analog	944-21-8	0.0029	
Hexazinone	51235-04-2	0.0129	
Iprodione	36734-19-7	0.387	
Isofenphos	25311-71-1	0.0034	
Malaoxon	1634-78-2	0.0298	
Malathion	121-75-5	0.027	
Methidathion	950-37-8	0.0058	
Parathion-methyl	298-00-0	0.015	
Metolachlor	51218-45-2	0.006	Herbicide.
Metribuzin	21087-64-9	0.006	
Myclobutanil	88671-89-0	0.008	
Paraoxon-methyl	950-35-6	0.0299	
Pendimethalin	40487-42-1	0.022	
Phorate	298-02-2	0.011	
Phorate, oxygen analog	2600-69-3	0.1048	
Phosmet	732-11-6	0.0079	
Phosmet oxon	3735-33-9	0.0511	
Prometryn	7287-19-6	0.0054	
Propyzamide	23950-58-5	0.004	
Terbufos	13071-79-9	0.017	
Terbufos, oxygen analog sulfone	56070-15-6	0.0676	
Terbutylazine	5915-41-3	0.0102	
Trifluralin	1582-09-8	0.009	

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Appendix 3. Other selected organic compounds analyzed in the Source Water-Quality Assessment studies in the South Platte River Basin and High Plains Regional Groundwater National Water-Quality Assessment study areas during 2003–2004.

[CASR, Chemical Abstracts Service Registry Number; µg/L, micrograms per liter; shading represents compound detected in the study; **Bold type** under compound heading indicates unregulated compound, for which no Federal and (or) State drinking-water standards have been established; regulated is a compound for which Federal and (or) State drinking-water standards have been established]

Regulated or unregulated compound	CASRN ¹	Minimum reporting level µg/L	Remark
Cotinine	486-56-6	1	
5-Methyl-1H-benzotriazole	136-85-6	2	
Anthraquinone	84-65-1	0.5	
Acetophenone	98-86-2	0.5	
Acetyl hexamethyl tetrahydronaphthalene (AHTN)	21145-77-7	0.5	
Anthracene	120-12-7	0.5	
Benzo[a]pyrene	50-32-8	0.5	
Benzophenone	119-61-9	0.5	
3- <i>tert</i> -Butyl-4-hydroxy anisole (BHA)	25013-16-5	5	
Caffeine	58-08-2	0.018	
Camphor	76-22-2	0.5	
Carbazole	86-74-8	0.5	
Cholesterol	57-88-5	2	
3-beta-Coprostanol	360-68-9	2	
N,N-diethyl-meta-toluamide (DEET)	134-62-3	0.5	
Bisphenol A	80-05-7	1	
Triethyl citrate (ethyl citrate)	77-93-0	0.5	
Fluoranthene	206-44-0	0.5	
Hexahydrohexamethylcyclopentabenzopyran (HHCb)	1222-05-5	0.5	
Indole	120-72-9	0.5	
Isoborneol	124-76-5	0.5	
Isophorone	78-59-1	0.5	Used as a solvent in some printing inks, paints, lacquers, and adhesives.
Isoquinoline	119-65-3	0.5	
d-Limonene	5989-27-5	0.5	
Menthol	89-78-1	0.5	
1-Methylnaphthalene	90-12-0	0.5	
2,6-Dimethylnaphthalene	581-42-0	0.5	
2-Methylnaphthalene	91-57-6	0.5	
Nonylphenol, diethoxy- (total)	26027-38-2	5	
Octylphenol, diethoxy	26636-32-8	1	
Octylphenol, monoethoxy-	26636-32-8	1	
<i>p</i>-Cresol	106-44-5	1	
4-Cumylphenol	599-64-4	1	
para-Nonylphenol (total)	84852-15-3	5	
4- <i>n</i> -Octylphenol	1806-26-4	1	
4- <i>tert</i> -Octylphenol	140-66-9	1	
Phenanthrene	85-01-8	0.5	
Phenol	108-95-2	0.5	Used primarily in the formation of phenolic resins. It is also used in the manufacture of nylon and other synthetic fibers.
Pentachlorophenol	87-86-5	2	

Appendix 3. Other selected organic compounds analyzed in the Source Water-Quality Assessment studies in the South Platte River Basin and High Plains Regional Groundwater National Water-Quality Assessment study areas during 2003–2004.—Continued

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Regulated or unregulated compound	CASRN ¹	Minimum reporting level µg/L	Remark
Tributyl phosphate	126-73-8	0.5	
Triphenyl phosphate	115-86-6	0.5	
Tris(2-butoxyethyl)phosphate	78-51-3	0.5	Used mainly as a component in floor polishes, a solvent in some resins, a viscosity modifier in plastisols, an antifoam and also as a plasticizer in synthetic rubber, plastics and lacquers.
Tris(2-chloroethyl)phosphate (TCEP)	115-96-8	0.5	
Pyrene	129-00-0	0.5	
Methyl salicylate	119-36-8	0.5	
3-Methyl-1(H)-indole (Skatole)	83-34-1	1	
beta-Sitosterol	83-46-5	2	
beta-Stigmastanol	19466-47-8	2	
Triclosan	3380-34-5	1	
Tris(dichloroisopropyl)phosphate (TCPP)	13674-87-8	0.5	

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