Changes in Nutrient and Pesticide Concentrations in Urban and Agricultural Areas of the South Platte River Basin, Colorado, Wyoming, and Nebraska, 1994–2000

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Abstract

As part of the National Water-Quality Assessment (NAWQA) Program, the U.S. Geological Survey (USGS) monitored two sites on the main-stem South Platte River— an urban site in Denver and a mixed urban/agricultural site near Kersey—to determine changes in nutrient and pesticide concentrations from 1994 through 2000. Concentrations of nitrate, nitrite, ammonia, and orthophosphorus decreased at the Denver site during the study period, likely due to an increase in instream dilution of wastewater-treatment plant (WWTP) discharge and upgrades at the WWTPs. In contrast, only concentrations of orthophosphorus decreased at the Kersey site; agricultural inputs between Denver and Kersey may have offset the observed decreases in other nutrients upstream. During the extreme low-flow conditions in 1994, when there was relatively little snowmelt to dilute instream pesticide concentrations, total median pesticide concentrations at both sites were the highest of the study period. During the less extreme conditions in 1997 through 2000, greater amounts of snowmelt likely led to lower total median pesticide concentrations at both sites. Because pesticide-use data are not available, the contribution of changes in the amount and type of pesticides applied on the land to changes in the concentration of pesticides in the river is not known but likely was substantial. In general, insecticides predominated at the Denver site, whereas herbicides predominated at the Kersey site.

INTRODUCTION

The South Platte River originates in the Rocky Mountains of central Colorado at the Continental Divide and flows about 450 miles northeast across the Great Plains to its confluence with the North Platte River at North Platte, Nebraska (fig.1). More than 2.8 million people currently (2002) live in the Front Range urban corridor along the base of the Rocky Mountains in the South Platte River Basin; the population increased by about 670,000 people from 1990 through 2000 (U.S. Census Bureau, 2000). On the plains downstream from the Denver metropolitan area, population densities are small and the land is used primarily for agriculture and livestock production.

The geologic and land-use diversity has had a profound effect on water-quality conditions within the basin. In 1991, the U.S. Geological Survey (USGS) began a study of the South Platte River Basin as part of the National Water-Quality Assessment (NAWQA) Program. The goals of the NAWQA Program are to assess the quality of surface water, ground water, and aquatic ecosystems throughout the Nation and to understand the primary natural and human factors affecting the quality of these resources. To help address water-quality issues of concern in the South Platte River Basin, the USGS monitored two sites on the main-stem South Platte River from 1994 through 2000 to determine long-term changes in nutrient and pesticide concentrations in urban and mixed urban/agricultural areas.

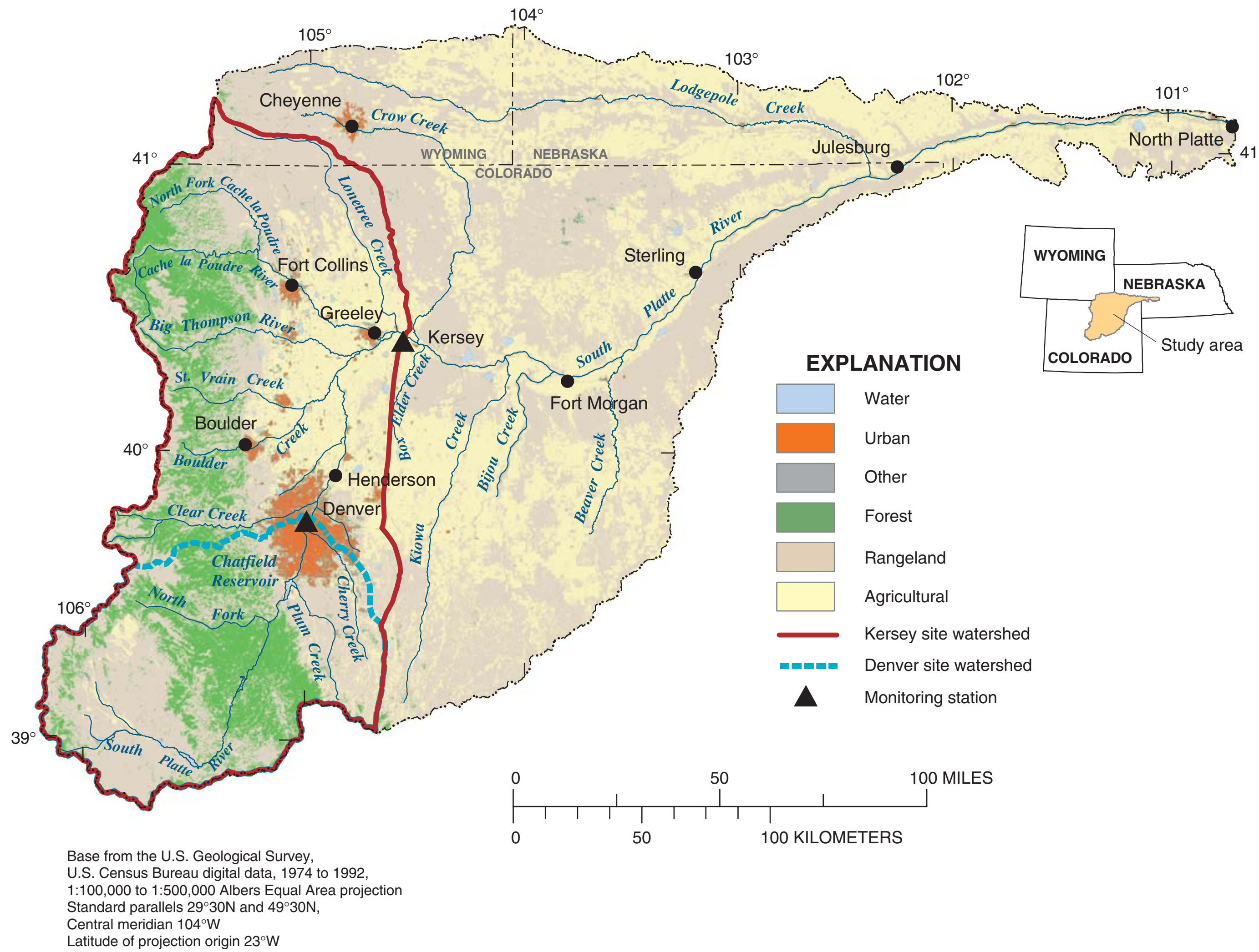

Figure 1. Land use in the South Platte River Basin varies from forested areas in the mountains, to urban areas along the Front Range corridor, and to agricultural areas in the plains. Different land uses can lead to different water-quality conditions throughout the basin.

The monitoring site on the South Platte River at Denver (USGS station number 06714000) is located downstream from the confluence of Cherry Creek and the South Platte River in downtown Denver (fig. 1). Most of the water at the site originates downstream from Chatfield Reservoir, where the land use is predominantly urban. Streamflow is derived primarily from urban base flow (wastewater-treatment-plant discharges and ground-water inflows), urban storm runoff, and reservoir releases (Litke and Kimbrough, 1998). From 1994 through 2000, substantial commercial and residential development in this already urbanized area increased the impervious surface area and drainage-pipe discharge to the river. This site is representative of urban land use.

Downstream from Denver, the South Platte River flows through predominantly agricultural land toward Kersey. The monitoring site on the South Platte River near Kersey (USGS station number 06754000) is located near the confluence of Lonetree Creek and the South Platte River (fig. 1). Streamflow at this site is derived, in varying degrees, from upstream wastewater-treatment-plant discharges, irrigation-return flow, snowmelt runoff, and urban runoff (Litke and Kimbrough, 1998). Because of the combination of sources, this site is representative of urban and agricultural land uses.

Most of the water at the monitoring site on the South Platte River at Denver originates downstream from Chatfield Reservoir, where the land use is primarily urban.

Water at the monitoring site on the South Platte River near Kersey is derived from a combination of urban and agricultural sources.

Why are we concerned about nutrients and pesticides?

Although nutrients such as nitrogen and phosphorus are necessary for plant and animal life, in excessive quantities they can accelerate the growth of aquatic plants and cause algal blooms (Wetzel, 1983). Algal blooms and excessive aquatic-plant growth may result in unsuitable habitat conditions for aquatic animals and waterfowl and can interfere with recreational activities such as fishing, swimming, and boating. The subsequent decay and decomposition of algae and other aquatic plants can cause odor and taste problems in drinking-water supplies and can consume dissolved oxygen, which can adversely affect fish and other aquatic life.

Pesticides used to kill weeds, insects, and other pests can have harmful effects on humans and the environment. Potential health effects on humans and aquatic life because of overexposure to certain pesticides include cancer and nervous-system disorders. Recent studies suggest that some pesticides can disrupt endocrine systems and affect reproduction by interfering with natural hormones (Fuhrer and others, 1999). Certain pesticides with low solubility in water and high resistance to degradation can accumulate in riverbed sediments and fatty tissue in fish and can persist in the environment for long periods of time. Often, contamination occurs as a mixture of pesticides, and little is known about the toxicity of these mixtures.

How do nutrients and pesticides reach rivers?

Nutrients are delivered to the South Platte River from point and nonpoint sources (fig. 2). Point sources of nutrients can be attributed to a single location, such as a wastewater discharge pipe. Nonpoint sources of nutrients are widely distributed over an area, such as storm runoff from agricultural fields and urban areas like lawns and golf courses, atmospheric deposition, and ground-water discharge to the river. Approximately 67 percent of the total wastewater discharge to the South Platte River occurs upstream from Henderson, Colo., where the river flows through the Denver metropolitan area; another 28 percent of the wastewater discharge occurs between Henderson and Kersey (Litke, 1996). Downstream from Kersey, the influence of wastewater discharges decreases, and water is derived primarily from nonpoint agricultural sources in the plains.

Pesticides are delivered to the South Platte River largely from nonpoint sources (fig. 2). Potential sources include storm runoff from agricultural fields and urban areas, atmospheric deposition, and ground-water discharge to the river. Because of different pest-control needs in agricultural compared to urban areas, different pesticides are applied and in different amounts and combinations in the two areas. For example, atrazine primarily is used as a preemergent herbicide on corn, whereas diazinon commonly is used as a household insecticide (table 1). The amount of pesticide available to be carried in storm runoff to streams is greatest just after application, before the pesticide degrades in the environment or is assimilated by plants. Because the timing of application differs

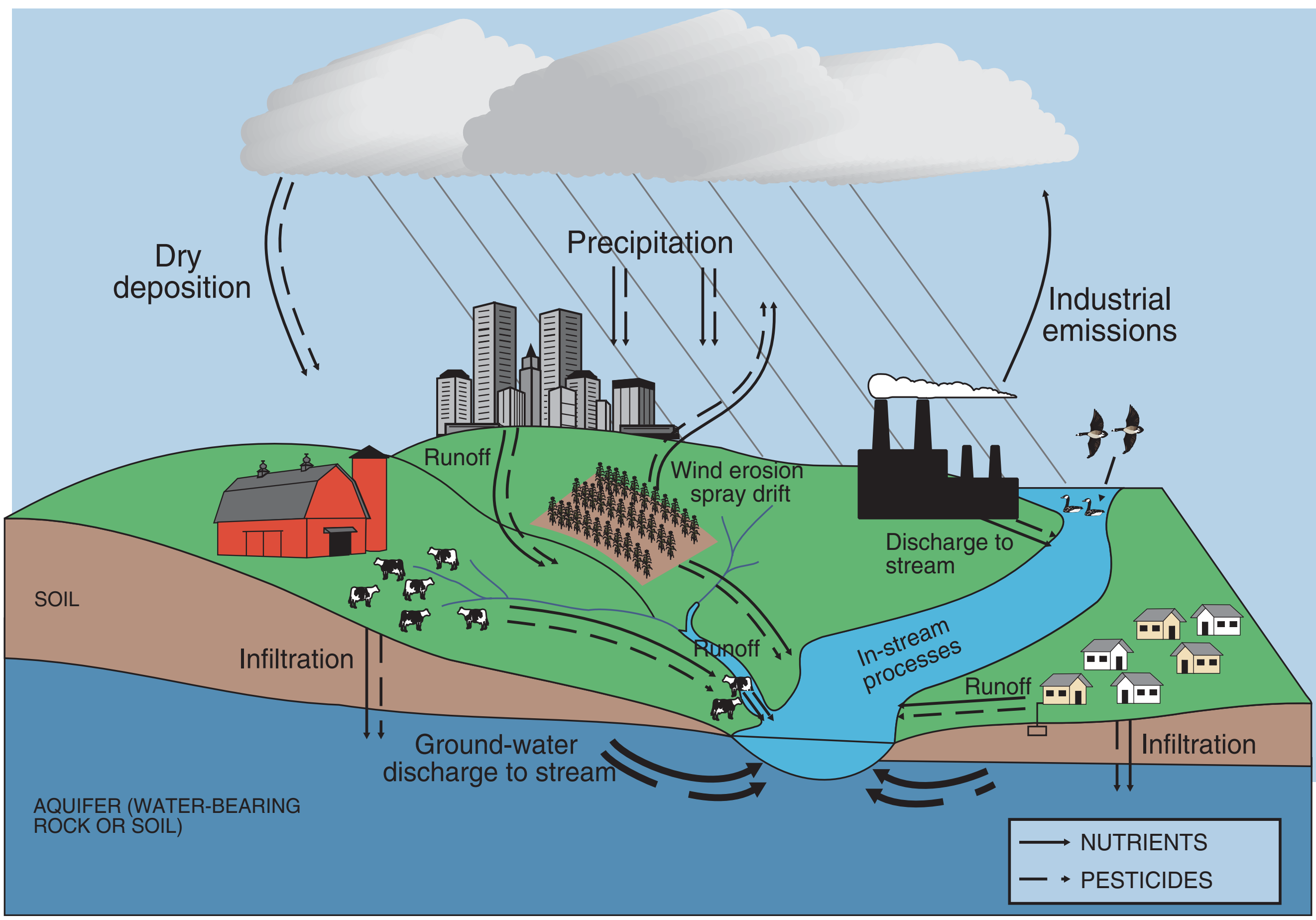

Figure 2. Nutrients and pesticides can reach the South Platte River from point sources, such as wastewater-treatment-plant discharge pipes, and from nonpoint sources, such as storm runoff from agricultural fields and suburban lawns.

Treated wastewater discharge to the South Platte River downstream from Denver is a source of nutrients.

Runoff from agricultural fields treated with pesticides and fertilizer is a source of nutrients and pesticides.

among pesticides, they often reach surface water during different months of the year. In addition, certain pesticides may appear in surface water for months after application because they are more resistant to degradation or because they are transported through ground water.

Some efforts have been made to reduce the transport of nutrients and pesticides to rivers. To control point-source pollution, many wastewater-treatment plants have implemented new technologies that more effectively remove nitrogen and phosphorus from wastewater. In addition, since 1970, 27 States and the District of Columbia have enacted mandatory bans on the use of phosphate detergents (Litke, 1999). The States in the South Platte River Basin do not have mandatory bans, but the detergent industry voluntarily phased out the use of phosphorus in domestic laundry detergent throughout the Nation by about 1994.

To control nonpoint-source pollution, many best management practices (BMPs) have been implemented to minimize concentrations of nutrients and pesticides reaching the river. Nonstructural BMPs, designed in part to minimize the application of fertilizers and pesticides, include educational programs, low-impact development that maintains predevelopment hydrology, and the creation of new pesticides that may have less of an effect on the environment. Structural BMPs, designed to reduce surface runoff of nutrients and pesticides to rivers, include sediment fences, constructed wetlands, and stormwater-retention ponds. With some structural BMPs, however, nutrient- or pesticide-rich runoff that is diverted away from rivers can infiltrate to ground water, which can eventually discharge to a river. Because ground water moves slowly, it may take many years to assess the effectiveness of the BMPs.

Table 1. The eight most common pesticides and pesticide degradation products detected during the study in the South Platte River at Denver and near Kersey, Colorado

[n/a, not applicable; H, herbicide; I, insecticide; D, degradation product]

Pesticide	Type	Common trade name	Common use
Atrazine	H	Aatrex	Weed control primarily on corn crops.
Carbaryl	I	Sevin, Chipco	Insect control primarily on lawns, pets, livestock, and rangeland.
DCPA	H	Dacthal	Weed control primarily on onion crops.
Deethylatrazine	D	n/a	n/a
Diazinon	I	Basudin, Gardentox	Insect control primarily in households.
Metolachlor	H	Dual	Weed control primarily on corn crops.
Prometon	H	Pramitol	Weed control on bare-ground, noncropped areas.
Tebuthiuron	H	Spike, Graslan	Weed control on bare-ground, noncropped areas.

How have nutrient concentrations changed in the South Platte River at Denver and near Kersey from 1994 through 2000?

Water samples for nutrient analyses were collected from the South Platte River at Denver and near Kersey approximately monthly from 1994 through 2000. Nitrogen exists in natural waters as one of several different forms depending on the source and the environmental conditions. Common forms include nitrite, nitrate, ammonia, and organic nitrogen. Because nitrogen is readily converted from one form to another in a stream, identifying sources of nitrogen at a single monitoring station is difficult. However, nitrogen from specific sources enters streams in characteristic forms. Sources of ammonia and organic nitrogen include the decay of organic material such as plant material and animal wastes and urban and industrial disposal of sewage and organic waste. Large amounts of ammonia and organic nitrogen also are applied in agricultural and urban areas as fertilizer. Ammonia and organic nitrogen can be transformed by bacteria into nitrite and nitrate, the more mobile forms of nitrogen. Nitrate derived from agricultural fertilizer, animal waste, or decaying plant material can more readily infiltrate ground water, which in turn can discharge to streams. Nitrogen oxides discharged to the atmosphere by plants and the burning of fossil fuels are transformed to nitrate that is present in precipitation (Wetzel, 1983).

Like nitrogen, phosphorus is present in natural waters in several different forms, primarily as orthophosphorus and organic phosphorus. Sources of orthophosphorus include weathering of natural soils and rocks and wastewater-treatment-plant discharge. Orthophosphorus also is applied in agricultural and urban areas as fertilizer; this form of phosphorus binds strongly to soil and is not very mobile on its own. Erosion of soil, however, may lead to high concentrations of sediment-associated phosphorus in streams. Orthophosphorus can be taken up by plants and animals and ultimately transformed into organic phosphorus. Wastewater-treatment-plant discharge also is a source of organic phosphorus.

Concentrations of the different forms of nitrogen and phosphorus at the two monitoring stations from 1994 through 2000 are shown in figure 3. During the study period, the median concentration of total nitrogen at the Denver site was 4.8 milligrams per liter (mg/L), most of which was composed of nitrate. The median concentration of total phosphorus was 0.56 mg/L, most of which was composed of orthophosphorus. The median concentrations of total nitrogen and total phosphorus were higher at the Kersey site: 7.4 mg/L for nitrogen and 0.75 mg/L for phosphorus. As with the Denver site, most of the nitrogen at the Kersey site was in the form of nitrate, and most of the phosphorus was in the form of orthophosphorus, but there also was slightly more ammonia at the Kersey site than at the Denver site. The higher nutrient concentrations at the Kersey site may have resulted from wastewater-treatment-plant discharges and agricultural fertilizer application between Denver and Kersey. At both sites, median total phosphorus concentrations exceeded the limit of 0.1 mg/L recommended by the U.S. Environmental Protection Agency (USEPA) for the prevention of nuisance plant growth in streams (U.S. Environmental Protection Agency, 1986). During the study period, measured nitrate concentrations at the Denver site twice exceeded the maximum contaminant level of 10 mg/L established by the USEPA for drinking water (U.S. Environmental Protection Agency, 1986).

Trends are overall increases or decreases in a measurement such as concentration during a specified period. Trends in nutrient concentrations can be affected by BMPs or wastewater-treatment-plant upgrades, which are designed to achieve downward trends. In many cases, concentration trends also are affected by changes in streamflow. If a point source, such as discharge from a wastewater-treatment plant, is the dominant nutrient source to a stream, dilution

> Nutrients in the South Platte River at an urban site near Denver and at a mixed urban/agricultural site near Kersey are derived from different sources, contributing to different nutrient concentrations at the two sites. Median concentrations of nitrogen and phosphorus in the river near Kersey were higher than concentrations near Denver during the study period.

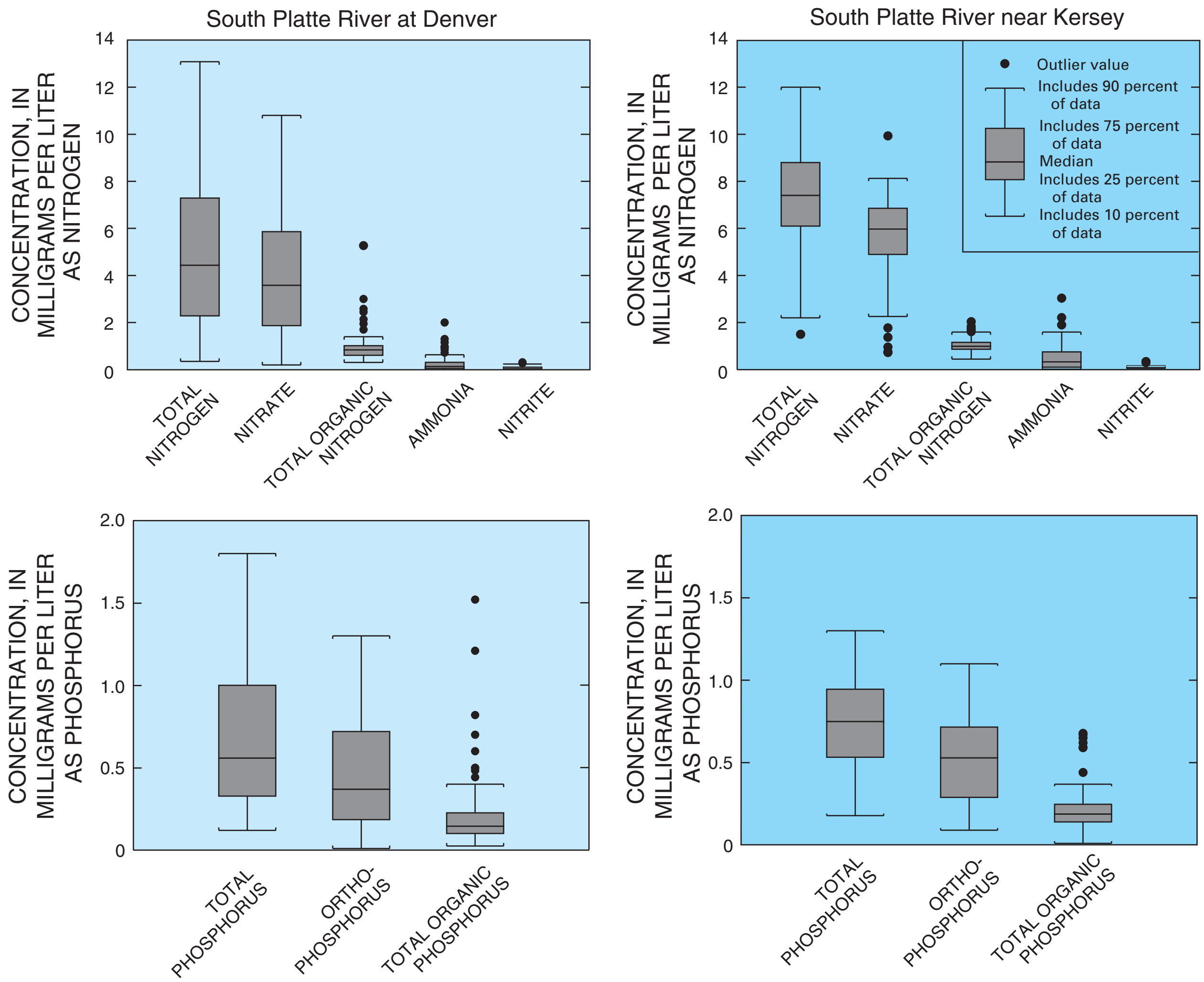

Figure 3. Median nitrogen and phosphorus concentrations in the South Platte River were higher in the mixed urban/agricultural area near Kersey than in the urban area at Denver from 1994 through 2000. The higher concentrations at the Kersey site may have been the result of wastewater-treatment-plant discharge and agricultural fertilizer application that occurred in the basin between Denver and Kersey.

from an increase in streamflow may cause a downward trend in nutrient concentrations. In contrast, if a nonpoint source, such as runoff from agricultural land, is the dominant nutrient source, increased streamflow from an increase in stormwater runoff may cause an upward trend in nutrient concentrations. Sometimes, a decrease in nutrient concentrations that results from a BMP can be offset by an increase in concentrations that results from higher streamflow.

Trends in nutrient concentrations in the South Platte River from 1994 through 2000 were obtained by using the Seasonal-Kendall trend test (Hirsch and Slack, 1984; Stevens and Sprague, 2003). These trends account for all factors that affect instream nutrient concentrations, including streamflow and BMPs. To help determine the influence of streamflow on trends in nutrient concentrations, trends in streamflow also were determined by using the Seasonal-Kendall trend test.

Concentrations of nitrate, nitrite, ammonia, and orthophosphorus decreased at the Denver site from 1994 through 2000 (table 2). Streamflow increased during this period, and the concentration decreases likely resulted from the corresponding instream dilution of nutrients being discharged from wastewater-treatment plants, the largest source of nutrients in the river at this location (Litke, 1996). Upgrades to the treatment plants designed to reduce nutrient

Table 2. Trends in streamflow and concentrations of selected constituents in the South Platte River at Denver and near Kersey, Colorado, from 1994 through 2000

[NS, nonsignificant; trends were considered significant when the p-value was less than 0.1]

Constituent or property	Denver	Kersey
Mean monthly streamflow	UP	UP
Dissolved nitrate	DOWN	NS
Dissolved nitrite	DOWN	NS
Dissolved ammonia	DOWN	NS
Total organic nitrogen	NS	NS
Dissolved orthophosphorus	DOWN	DOWN
Total organic phosphorus	NS	NS
Suspended sediment	UP	UP

concentrations in effluent also may have been a factor. In contrast, concentrations of suspended sediment, which reaches the river largely through erosion from nonpoint sources such as construction sites and bare-ground areas, increased during this period in response to increases in construction and storm runoff. Nutrients, particularly phosphorus, can bind to sediment and also be transported to the river during erosion, but the lack of a similar increase in nutrient concentrations suggests that nonpoint sources of nutrients were small compared to point sources.

At the Kersey site, concentrations of orthophosphorus decreased and concentrations of suspended sediment increased from 1994 through 2000 (table 2). Streamflow also increased during this period. The decrease in concentrations of orthophosphorus probably resulted from the instream dilution of wastewater-treatment-plant discharge, likely still one of the largest sources of orthophosphorus in the river at this site. Concentrations of suspended sediment may have increased during this period in response to the increase in streamflow and storm runoff from agricultural and urban areas.

Nutrients in the South Platte River at Denver and near Kersey are derived from different sources, which contributes to different trends in nutrient concentrations at the two sites. Because discharge from wastewater-treatment plants is the largest source of nutrients to the river at the Denver site, instream dilution and treatment-plant upgrades during the study period would have had more of an effect on nutrient concentrations in the South Platte River at Denver than near Kersey. Farther downstream toward Kersey, agricultural inputs become a larger source of nutrients, which may have begun to offset the decreases in nutrient concentrations observed upstream during the study period.

How have pesticide concentrations changed in the South Platte River at Denver and near Kersey from 1994 through 2000?

Water samples for pesticide analyses were collected during 1994 and the 4-year period from 1997 through 2000. Because of the gap in the pesticide data set in 1995 and 1996, statistical trend analysis was not appropriate. Instead, broad changes in the pesticide mixture at each site were examined and compared.

The concentration of pesticides in rivers is influenced by several environmental and anthropogenic factors, such as the amount of precipitation, which is reflected in streamflow, and the pesticide application rates in areas that drain to the stream. Pesticide samples generally were collected for this study from May through September, the time of year when application rates and streamflow typically are elevated. Therefore, these pesticide concentrations are not representative of an entire year.

Samples from the South Platte River were collected bimonthly at Denver and monthly near Kersey. Because of the difference in sampling frequency, median concentrations were used to compare changes in the distribution of pesticides

Concentrations of nitrate, nitrite, ammonia, and orthophosphorus decreased at the Denver site during the study period, and concentrations of orthophosphorus decreased at the Kersey site. These trends were related to changes in streamflow, nutrient sources, and management practices implemented in different parts of the basin.

between the two sites. To examine changes in the distribution of pesticides over time, the data from each of the years for which data were available were grouped. Total median pesticide concentrations were calculated for each site and year by summing the median concentration of all pesticides for which analyses were made during this study. This total should not be viewed as all-inclusive because not every pesticide used in the South Platte River Basin during the study period was included in the analyses for this study. The analysis ultimately focused on the four pesticides that composed the largest portion of the total median pesticide concentration at each site during each year. Accounting for overlap, this focus resulted in a list of eight pesticides (table 1).

The largest difference between the two sites was the predominance of insecticides in the South Platte River at Denver and the predominance of herbicides in the South Platte River near Kersey (fig. 4). Atrazine, its degradation product deethylatrazine, and metolachlor composed the largest portion of the total median pesticide concentration near Kersey. Both atrazine and metolachlor were among the most heavily applied pesticides in agricultural areas of the South Platte River Basin (Mike Majewski, U.S. Geological Survey, written commun., 1997). In contrast, carbaryl and diazinon composed a much larger portion of the total median pesticide concentration at the Denver site compared to the Kersey site. Pesticide-use data currently are not available for the Denver area, so it is not possible to evaluate the link between urban pesticide use and the concentrations detected in the river at Denver. In other major river basins throughout the United States, insecticides such as diazinon commonly occur at detectable concentrations in rivers influenced by urban drainage (Larson and others, 1997). Carbaryl, prometon, and diazinon also occurred at measurable concentrations in the river near Kersey, which is indicative of the mixed urban and agricultural sources at this site.

In addition to broadly comparing pesticide mixtures at the two sites, changes in pesticide concentrations from year to year were compared. Pesticide concentrations in the river vary temporally because of changes in environmental conditions such as precipitation and streamflow and because of changes in the amount and type of pesticides applied. Streamflow at Denver is derived in part from snowmelt, which can dilute instream pesticide concentrations; therefore,

Insecticides like carbaryl and diazinon predominated at the Denver site, whereas herbicides like atrazine and metolachlor predominated at the Kersey site.

concentrations at Denver were dependent on the amount of snowmelt each year. In contrast, streamflow at Kersey primarily is derived both from snowmelt and, to a larger degree than at Denver, from localized storms, which either can dilute or elevate instream pesticide concentrations depending on the amount of water in storm runoff and the amount of pesticide carried in that water. Consequently, during the extreme low-flow conditions in 1994 (fig. 5), when there was relatively little snowmelt, total median pesticide concentrations at both sites were high (fig. 4). During the less extreme conditions in 1997 through 2000, greater amounts of snowmelt led to lower total median pesticide concentrations at both sites. Near Kersey, where more of the water came from storm runoff, concentrations fluctuated more than at Denver in response to differences in the number of large storms. Because pesticide-use data are not available, the contribution of changes in the amount and type of pesticides applied on the land to changes in the concentration of pesticides in the river is not known but likely was substantial.

The mixture of pesticides also varied during the period of study (fig. 4). At the Denver site, the proportion of diazinon increased during the study period. The largest proportion of carbaryl was observed in 1994 and the smallest proportion in 2000; however, the proportion varied during the intervening years. At the Kersey site, the proportion of DCPA decreased sharply from 1994 through the following years, while the proportion of prometon and deethylatrazine generally increased. During 1998, a large increase in the proportion of carbaryl also was observed. Changes at both sites may be related to the rate at which the pesticides are applied, their ability to bind to soil, the speed at which they break down in the environment, and the timing of a rainstorm and surface runoff after application.

The relative total median pesticide concentrations at the Denver site compared to the Kersey site

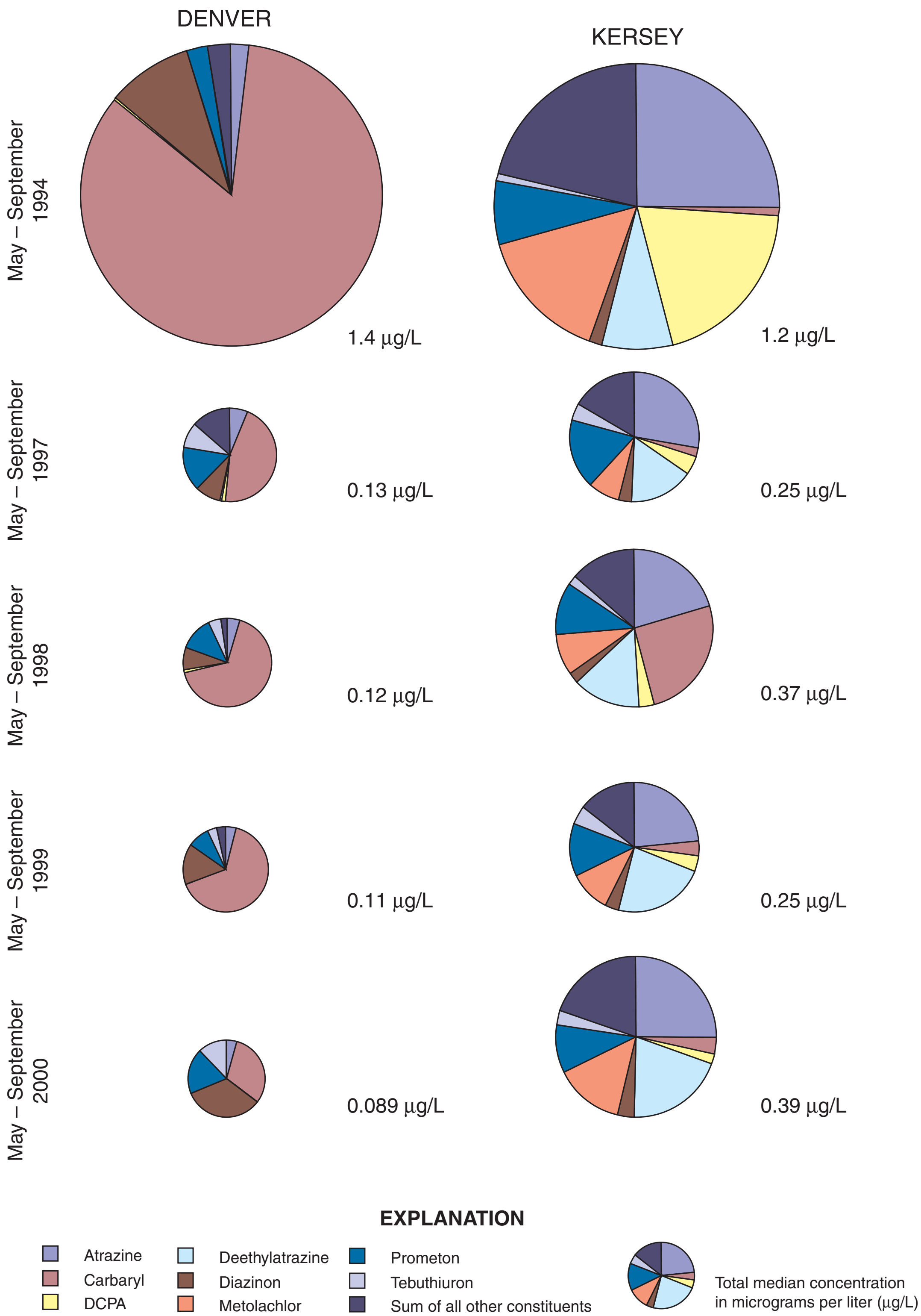

Figure 4. A comparison between the total median pesticide concentration and the mixture of pesticides in the South Platte River at Denver and near Kersey indicates that extremely low streamflow during 1994 contributed to the highest concentrations during the study period. Insecticides like carbaryl and diazinon predominated at the urban Denver site, whereas herbicides like atrazine and metolachlor predominated at the mixed urban/agricultural Kersey site.

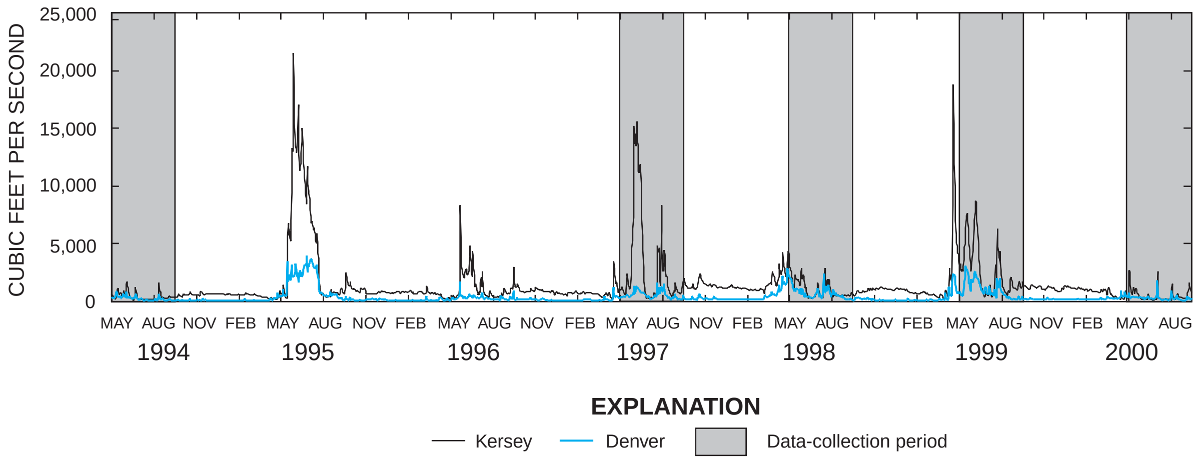

Figure 5. Pesticide data were collected for this study from May through September in 1994, 1997, 1998, 1999, and 2000. Streamflow fluctuated in the South Platte River during these years – streamflow during 1994 was extremely low, whereas streamflow from 1997 through 2000 covered a range more typical of the region. These fluctuations affected instream pesticide concentrations.

also varied between the low-flow year and subsequent years. During 1994, the total median pesticide concentration was slightly higher at the Denver site than at the Kersey site (fig. 4), possibly because the impervious surfaces in urban areas – parking lots and roads, for example – allowed less water to infiltrate into the ground, leading to more runoff of pesticides to the river even during this extremely low-flow year. In later years, however, the total median pesticide concentrations were higher at the Kersey site. These results suggest that during years with average or high streamflow, higher concentrations of pesticides reach the river from mixed urban/agricultural areas, whereas during years with low streamflow, higher concentrations of pesticides reach the river from urban areas. The reasons for this have not been well established but likely include differences in the amount of pesticides applied and changes in the amount of storm runoff and instream dilution in each area.

Median pesticide concentrations were slightly higher at the Denver site than at the Kersey site in 1994. In later years, however, median pesticide concentrations were higher at the Kersey site. The highest median pesticide concentrations at both sites occurred in 1994, when streamflow was lowest.

What can be done to further reduce the concentrations of nutrients and pesticides in the South Platte River?

Nutrients and pesticides in the South Platte River are a concern to humans and aquatic life. From 1994 through 2000, some progress was made in reducing nutrient and pesticide concentrations, but increases in streamflow at times counteracted and at times enhanced decreases in nutrient and pesticide concentrations. Because the variation in streamflow is in part natural, additional efforts are necessary to ensure further reductions. The combination of urban and agricultural sources in the South Platte River Basin means that efforts to manage nutrients and pesticides in the river will need to focus both on point and nonpoint sources. Potential management strategies include further reducing point-source concentrations, improving and implementing BMPs aimed at controlling runoff from nonpoint sources in urban and agricultural areas, improving emissions from automobiles and powerplants that discharge nitrogen into the atmosphere, and reducing home and commercial use of fertilizers and pesticides. Implementing these strategies could lead to reductions in nutrients and pesticides reaching the South Platte River in future years.

REFERENCES

Fuhrer, G.J., Gilliom, R.J., Hamilton, P.A., Morace, J.L., Nowell, L.H., Rinella, J.F., Stoner, J.D., and Wentz, D.A., 1999, The quality of our Nation's waters—Nutrients and pesticides: U.S. Geological Survey Circular 1225, 82 p.

Hirsch, R.M., and Slack, J.R., 1984, A nonparametric trend test for seasonal data with serial dependence: Water Resources Research, v. 20, no. 6, p. 727–732.

Larson, S.J., Capel, P.D., and Majewski, M.S., 1997, Pesticides in surface waters—Distribution, trends, and governing factors: Chelsea, Mich., Ann Arbor Press, 373 p.

Litke, D.W., 1996, Sources and loads of nutrients in the South Platte River, Colorado and Nebraska, 1994–95: U.S. Geological Survey Water-Resources Investigations Report 96–4029, 31 p.

Litke, D.W., 1999, Review of phosphorus control measures in the United States and their effects on water quality: U.S. Geological Survey Water-Resources Investigations Report 99–4007, 38 p.

Litke, D.W., and Kimbrough, R.A., 1998, Water-quality assessment of the South Platte River Basin, Colorado, Nebraska, and Wyoming—Environmental setting and water quality of fixed sites, 1993–95: U.S. Geological Survey Water-Resources Investigations Report 97–4220, 61 p.

Stevens, M.R., and Sprague, L.A., 2003, Hydrology and water-quality assessment of Muddy Creek and Wolford Mountain Reservoir near Kremmling, Colorado: U.S. Geological Survey Water-Resources Investigations Report 03–4073.

U.S. Census Bureau, 2000, Census 2000 redistricting data summary file: U.S. Census Bureau Technical Documentation Public Law 94–171, 223 p.

U.S. Environmental Protection Agency, 1986, Quality criteria for water—1986: U.S. Environmental Protection Agency report EPA 440/5–86–001 [variously paged].

Wetzel, R.G., 1983, Limnology: Philadelphia, W.B. Saunders, 767 p.