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Significant Findings of Water-Quality Studies and Implications for Cheney Reservoir Watershed, South-Central Kansas, 1996–2001

—*Larry M. Pope*

Water-quality issues in the Cheney Reservoir watershed were investigated from 1996–2001 as part of a cooperative effort between the U.S. Geological Survey (USGS) and the city of Wichita, Kansas. Water quality in the Cheney Reservoir watershed is important because much of the population of the area, which includes the Wichita metropolitan area, relies on Cheney Reservoir as a drinking-water source and for recreational activities. Water-quality studies conducted during the investigation addressed the transport of important water-quality constituents that included nutrients (nitrogen and phosphorus species), pesticides, bacteria, and suspended solids. Conclusions drawn for most water-quality studies conducted in the Cheney Reservoir watershed were the result of samples collected at six surface-water-quality sampling sites (five upstream and one downstream from Cheney Reservoir) and reservoir-sediment and watershed-soil studies (fig. 1).

The water-quality studies are documented in the reports referenced in this fact sheet. Reports of all of these studies are available on the World Wide Web at ***http://ks.water.usgs.gov/Kansas/qw/cheney/***

Overview

- **Mean concentrations of nitrate in streamflow were much less than drinking-water criteria.**
- **Mean concentrations of phosphorus in streamflow exceeded the established water-quality goal at all sampling sites.**
- **Agricultural activities have accounted for 65 percent of the phosphorus transported to Cheney Reservoir.**
- **Substantial reductions in phosphorus transported to Cheney Reservoir may involve a combination of approaches such as reducing phosphorus application and changes in land-use, land-management, and agricultural practices.**
- **Median concentrations of pesticides in streamflow were less than drinking-water criteria.**
- **Numbers of fecal coliform bacteria in streams were large during runoff but were less than water-quality criteria in Cheney Reservoir.**
- **Sediment accumulation in Cheney Reservoir was less than expected.**

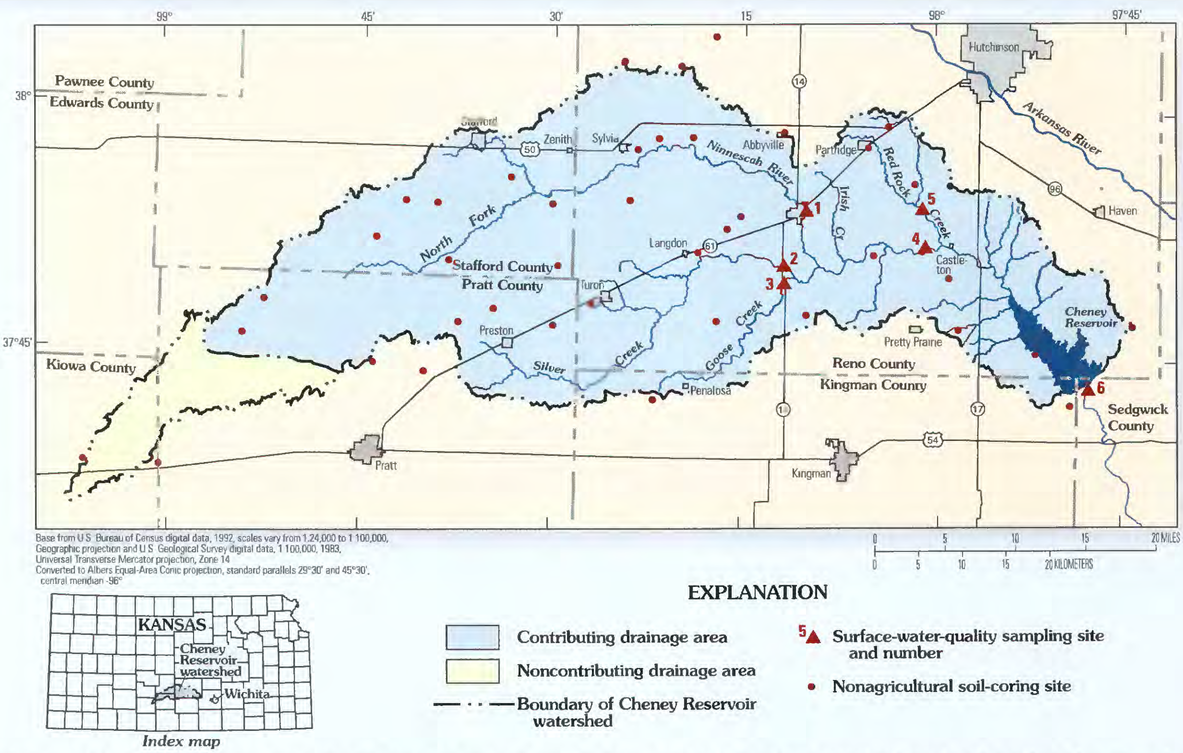

Figure 1. Location of Cheney Reservoir watershed, surface-water-quality sampling sites, and nonagricultural soil-coring sites, south-central Kansas.

Nutrients

- **Mean concentrations of nitrate were small compared to the U.S. Environmental Protection Agency (USEPA) drinking-water criterion of 10 mg/L.** Among the five surface-water-quality sampling sites upstream from Cheney Reservoir, mean concentrations of nitrate ranged from 0.43 (sampling site 2, fig. 1) to 1.6 mg/L (milligrams per liter) (sampling site 5) in surface-water samples collected during 1997–2000. However, mean concentrations of nitrate in water from four of the five sites were larger than the national mean background concentration of 0.6 mg/L, which may indicate that nitrate concentrations in streamflow in the Cheney Reservoir watershed are enriched as a result of agricultural activities (Milligan and Pope, 2001).

- **Mean concentrations of total phosphorus exceeded water-quality goals.** The long-term mean stream-water-quality goal of 0.10 mg/L for total phosphorus established by the Cheney Reservoir Watershed Task Force Committee was exceeded by mean concentrations of total phosphorus in water samples collected during 1997–2000 from all five surface-water-quality sampling sites upstream from Cheney Reservoir (fig. 2). These mean concentrations ranged from 0.23 (sampling site 2, fig. 1) to 0.50 mg/L (sampling site 5) and were substantially larger than the 0.10-mg/L national mean background concentration of total phosphorus in streams, which indicates enrichment by agricultural activities or large natural concentrations in soils (Milligan and Pope, 2001). Historically (1965–98), however, the mean total phosphorus concentration in the surface-water inflow to Cheney Reservoir was 0.76 mg/L as calculated on the basis of phosphorus deposited in the reservoir sediment (Mau, 2001). The implication of these relatively large mean phosphorus concentrations is that phosphorus input to Cheney Reservoir is sufficient to produce algal blooms (excessive growth of algae), possible taste-and-odor problems in treated drinking water, and potentially could reduce the aesthetic and recreational appeal of the reservoir.

- **Phosphorus concentrations have been increasing over time.** An analysis of reservoir bottom sediment indicated an increasing trend (since construction of the reservoir in 1965) in total phosphorus concentrations in water from the Cheney Reservoir watershed. This trend probably is related to human activities such as fertilizer use in crop production, which more than doubled between 1965 and 1996 (Mau, 2001).

- **The amount of phosphorus annually transported from the watershed varied.** Annual fluctuations in the amount of phosphorus transported by streams in the watershed resulted, in large part, from variability in precipitation and resulting runoff. Wetter years produced more phosphorus transport. Most of the annual phosphorus transport to Cheney Reservoir occurred during runoff (high-flow) conditions. For example, during 1997–2000, 72 percent of the phosphorus transport in streamflow at sampling site 4 (fig. 1) occurred during runoff (Pope and others, 2002). The estimated mean annual phosphorus yield for the entire Cheney Reservoir watershed for 1997–98 was 0.20 pound per acre (Pope and Milligan, 2000). Historically (1965–98), however, the mean annual phosphorus yield of the watershed was estimated at 0.38 pound per acre (Mau, 2001). Estimated mean annual yields from watersheds of other reservoirs in Kansas have ranged from 0.02 to 1.76 pounds per acre.

- **Agricultural activities accounted for 65 percent of the phosphorus transported to Cheney Reservoir.** A comparison of the historical (1965–98) mean concentrations of phosphorus in sediment transported to Cheney Reservoir with the mean concentration of phosphorus in soil from 43 nonagricultural sites (fig. 1) in the Cheney Reservoir watershed indicated that agricultural activities increased the transport of phosphorus into Cheney Reservoir 2.9 times greater than that expected under natural conditions of phosphorus in soil. It was estimated that during 1965–98, 8.4 million pounds of phosphorus were transported to Cheney Reservoir. Ninety-two (92) percent of this phosphorus was deposited in the bottom sediment of the reservoir. The amount of phosphorus transported to Cheney Reservoir related to agricultural activities (65 percent of the total) was calculated from the total amount transported (8.4 million pounds) and the agricultural-enrichment factor (2.9). The implication of this large percentage of agriculturally related phosphorus is that a

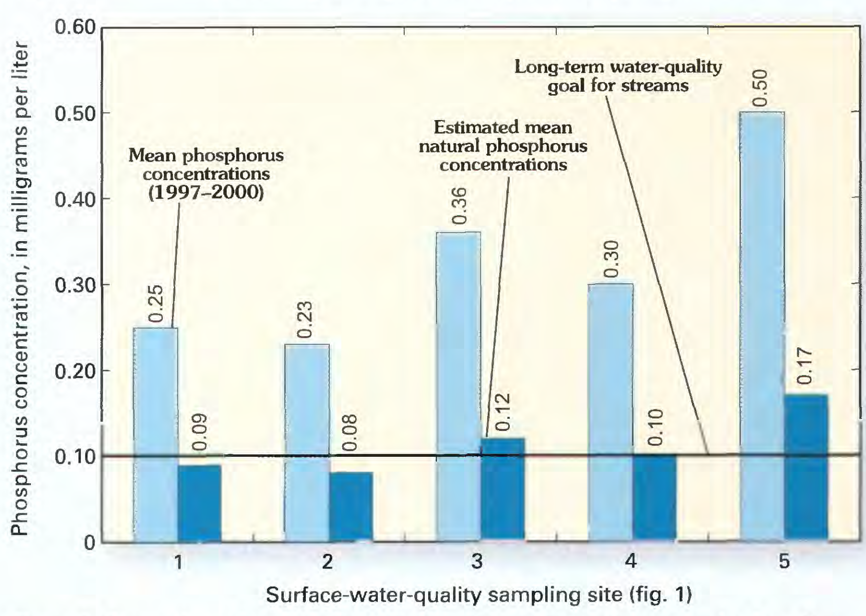

Figure 2. Comparison of mean phosphorus concentrations in water samples from five surface-water-quality sampling sites in Cheney Reservoir watershed to mean concentrations estimated on the basis of an agricultural-enrichment factor of 2.9. The long-term water-quality goal for phosphorus in streams was established by the Cheney Reservoir Watershed Task Force Committee.

large potential exists for reducing phosphorus transport to Cheney Reservoir by changing agricultural activities (Pope and others, 2002).

- **Substantial reduction in phosphorus transported to Cheney Reservoir may involve a combination of approaches such as reducing phosphorus application and changes in land-use, land-management, and agricultural practices.** To determine if reductions in phosphorus application alone would reduce mean concentrations of total phosphorus in streams to acceptable levels (equal to or less than 0.10 mg/L), the agriculturally affected long-term (1997–2000) mean concentrations presented in figure 2 were divided by the agricultural-enrichment factor (2.9). These calculations produced estimated long-term mean concentrations of total phosphorus under natural concentrations of phosphorus in watershed soil (fig. 2). These estimated concentrations indicate that even under natural concentrations of phosphorus in watershed soil two (sampling sites 3 and 5, fig. 1) of the five surface-water-quality sampling sites in the Cheney Reservoir watershed still may not meet the long-term water-quality goal of 0.10 mg/L. The implication of this finding is that in order to meet water-quality goals for total phosphorus in the watershed, a combination of approaches such as reducing phosphorus application and changes in land-use, land-management, and agricultural practices may be involved (Pope and others, 2002).

Pesticides

- **The occurrence of pesticides in surface water of the Cheney Reservoir watershed is widespread.** At least one pesticide was detected in 99 percent of the streamflow samples collected between 1997 and 1999. Fifteen herbicides, one herbicide metabolite, and six insecticides were detected in streamflow samples from the Cheney Reservoir watershed. The herbicides alachlor, atrazine, and metolachlor were detected in 61, 99, and 96 percent, respectively, of all streamflow samples (Milligan and Pope, 2000).

- **Median concentrations of pesticides generally were small and less than drinking-water criteria.** Median concentrations of alachlor and atrazine were less than their respective Maximum Contaminant Levels (MCLs) established by the U.S. Environmental Protection Agency (USEPA) (fig. 3). An MCL has not been established for metolachlor. The variability in median concentrations of alachlor, atrazine, and metolachlor among the six surface-water-quality sampling sites probably is the result of variations in pesticide usage, amount of precipitation and runoff, topography, agricultural practices, and soil characteristics such as particle-size composition, porosity, and erodibility among the subwatershed areas represented by the sampling sites (Milligan and Pope, 2000).

- **Potential adverse human health risks appear small.** The implication of long-term exposure to small

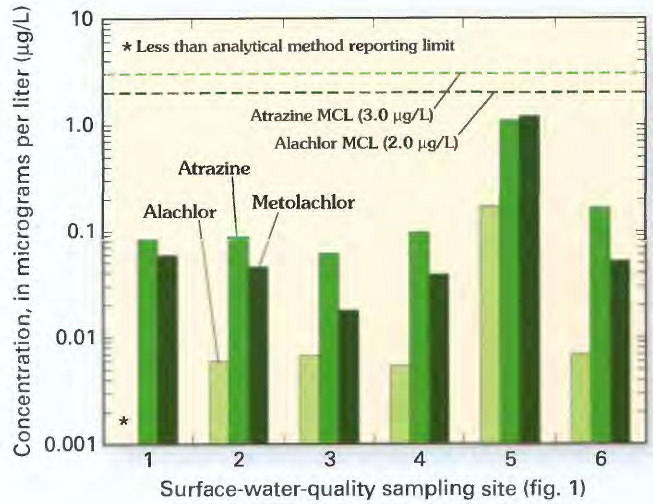

Figure 3. Comparison of median concentrations of the three most commonly detected pesticides (alachlor, atrazine, and metolachlor) in water from surface-water-quality sampling sites in Cheney Reservoir watershed, 1997–99, and Maximum Contaminant Levels (MCLs) established by the U.S. Environmental Protection Agency.

concentrations of pesticides in most streamflow samples for the population that relies on Cheney Reservoir as a drinking-water source is not of great concern on the basis of current (2001) water-quality criteria. However, the long-term effects of small concentrations of pesticides on aquatic life are not well known and may be an issue within the watershed (Milligan and Pope, 2000).

Bacteria

- **Bacteria of fecal origin are common in streams of the Cheney Reservoir watershed.** The sanitary quality of water and its use as a public drinking-water supply and for recreation were evaluated on the basis of fecal coliform bacteria densities. Fecal coliform bacteria were detected in streamflow samples from all surface-water-quality sampling sites in the watershed (fig. 4) (Mau and Pope, 1999).

- **Large fecal coliform densities are common in streams during runoff conditions.** Relatively large median fecal coliform densities were associated with runoff conditions at sampling sites upstream from Cheney Reservoir, and the median density at sampling site 3 was substantially larger than the 2,000-col/100 mL (colonies per 100 milliliters of water) water-quality criterion for secondary contact recreation (such as wading and fishing) established by the Kansas Department of Health and Environment (fig. 4). In contrast, median densities during base-flow (low-flow) conditions were substantially less than the 2,000-col/100 mL criterion in water from all five surface-water-quality sampling sites upstream from Cheney Reservoir. Fecal coliform densities are typically much greater in streams during runoff conditions because of nonpoint-source contributions from the watershed. These contributions can originate from deposition of fecal material by livestock and wildlife or from the use of manure as a soil amendment (Mau and Pope, 1999).

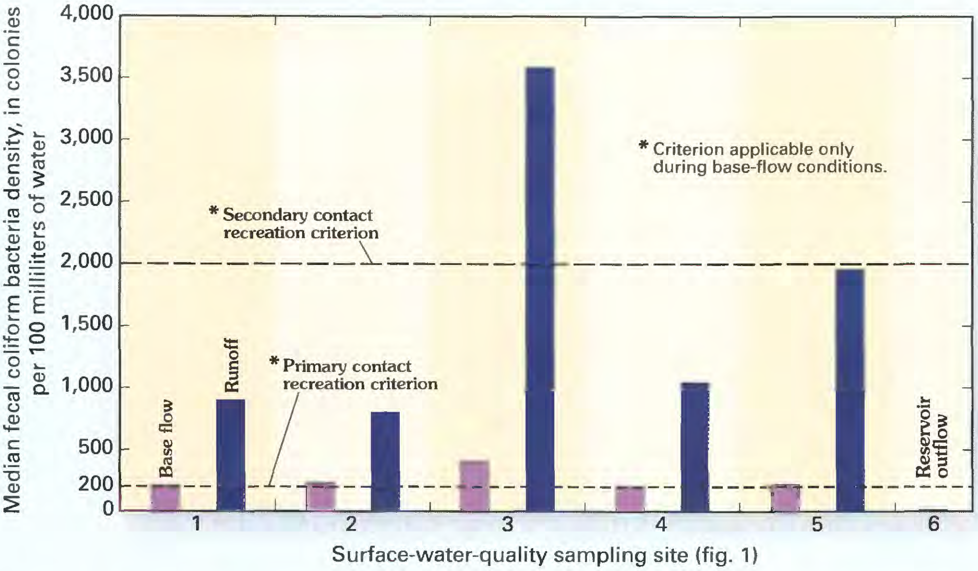

Figure 4. Comparison of median densities of fecal coliform bacteria in water from surface-water-quality sampling sites in Cheney Reservoir watershed during base-flow and runoff conditions for 1997–98 (primary and secondary contact recreation criteria from Kansas Department of Health and Environment).

- **Fecal coliform densities were much less in Cheney Reservoir than in its tributary streams.** The median fecal coliform density in water samples from the outflow of Cheney Reservoir (sampling site 6, fig. 1) for 1997–98 was about 11 col/100 mL, substantially less than the 200-col/100 mL water-quality criterion for primary contact recreation (such as swimming) (fig. 4). The relatively small median density of fecal coliform bacteria in the outflow from Cheney Reservoir is attributed to the fact that bacteria transported into the reservoir by tributary streams are subject to die off and predation by other organisms. The physical process of dilution by reservoir water and deposition also play a role in decreasing bacterial densities in reservoir outflow. The implication of the relatively small median density of fecal coliform bacteria is that water flowing out of the reservoir generally is of acceptable sanitary quality for swimming and other contact activities (Mau and Pope, 1999).

Suspended solids

- **Deposition of suspended solids in Cheney Reservoir was less than expected.** One of the principal concerns with the transport of suspended solids (sediment) into Cheney Reservoir is a loss of reservoir storage capacity. Cheney Reservoir has a sediment-trapping efficiency of 99 percent (Pope and others, 2002). Decreases in reservoir storage capacity can affect reservoir allocations used for flood control, drinking-water supplies, recreation, and wildlife habitat. Reservoirs in Kansas commonly were designed to provide 100 years of sediment deposition. As of 1998, 34 years of sediment deposition had occurred in Cheney Reservoir, which equates to 34 percent of the design life of the reservoir. However, only 27 percent of the allocated sediment storage capacity had been used. The implication of this finding is that although sediment is effectively trapped in Cheney Reservoir, it is accumulating at a rate less than expected, which may extend the useful life of the reservoir beyond 100 years. Also, this finding may be an indication that efforts to reduce erosion (transport of sediment) in the watershed have been effective (Mau, 2001).

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Sources and Concentrations of Phosphorus in the Cheney Reservoir Watershed, South-Central Kansas

—Larry M. Pope and Chad R. Milligan

Significant Findings

- ***Human-related activities in the predominantly agricultural watershed of Cheney Reservoir have substantial effects on the quality of water in the reservoir.***
- ***Agricultural activities have accounted for 65 percent of the phosphorus transported by streams to Cheney Reservoir, and most of that phosphorus was transported when streamflow consisted predominantly of runoff from agricultural fields.***
- ***On a long-term basis, surface water from five water-quality sampling sites in the watershed exceeded the established goal for phosphorus by about two to five times.***
- ***Substantial reductions in phosphorus concentrations in streams could involve a combination of approaches such as reducing the application of phosphorus in the watershed and more extensive implementation of land-management and agricultural practices to limit its movement to streams.***

Introduction

Phosphorus is a nutrient required by plants for growth and reproduction and often is added to agricultural soils to increase crop yields. However, the agricultural application of phosphorus historically has been greater than crop requirements and has led to a buildup of soil phosphorus (Carpenter and others, 1998). The buildup of soil phosphorus has increased the potential for phosphorus transport to surface water in runoff from agricultural fields (Sharpley and others, 1999).

Excess phosphorus in surface water may contribute to eutrophication (nutrient enrichment) of surface water, particularly lakes and reservoirs. Nutrient enrichment can overstimulate algal production creating algal blooms that may reduce the aesthetic and recreational value of the water, create taste-and-odor problems in drinking water, and, in severe cases, stress or kill aquatic organisms as a result of dissolved oxygen depletion or the release of toxins when algal blooms die (Sharpley, 1995).

The Cheney Reservoir watershed is a 933-square-mile contributing drainage area of Cheney Reservoir located on the North Fork Ninnescah River in an agricultural area of south-central Kansas (fig. 1). The watershed is used almost exclusively for crop and livestock production. Since 1965 when Cheney Reservoir was constructed, the percentage of the watershed used for crop production has averaged about 52 percent annually. Cattle inventories have averaged about 64,000 animals since 1965. Crop production and cattle inventories were estimated from county data presented in Kansas State Board of Agriculture and U.S. Department of Agriculture (1964–94) and Kansas Department of Agriculture and U.S. Department of Agriculture (1995–97).

The human population in the Cheney Reservoir watershed is less than 4,000, many of whom are associated with the approximately 1,000 farms in the watershed (Cheney

Heimerman Point at Cheney Reservoir, April 2001.

Reservoir Watershed Task Force Committee, written commun., 1996). Populations of the six largest towns in the watershed range from less than 200 to slightly more than 1,200 people (Helyar, 1994). Because of the small population in the watershed, the potential for substantial point-source contamination is small as determined in a previous low-flow investigation (Christensen and Pope, 1997).

Cheney Reservoir is a water-supply source for the city of Wichita and the surrounding area. Currently (2001), the city obtains 60 to 70 percent of its daily water supply for about 350,000 people from Cheney Reservoir (Jerry Blain, city of Wichita Water and Sewer Department, oral commun., 2000). Cheney Reservoir also provides for downstream flood control, wildlife habitat, and recreational opportunities.

In 1996, the U.S. Geological Survey entered into a cooperative study with the city of Wichita to assess the occurrence and transport of selected water-quality constituents, including phosphorus, within the Cheney Reservoir watershed. As part of that study, six surface-water-quality sampling sites were established in the watershed (fig. 1). Sites 1–5 were located on the main stem of the North Fork Ninnescah River or its tributary streams. Sampling site 6 was located immediately downstream from the Cheney Reservoir Dam.

Sources of Phosphorus

Because the Cheney Reservoir watershed is used almost exclusively for agricultural purposes, the two major sources of phosphorus are naturally occurring soil phosphorus and phosphorus contributed from agricultural activities (fertilizers and livestock waste). Quantification of these source contributions can provide information related to the extent of agricultural effects on the occurrence of phosphorus in streams of the watershed and the potential to achieve a meaningful reduction in the amount of phosphorus transported to Cheney Reservoir. On the basis of results from a previous investigation conducted during low flow (Christensen and Pope, 1997), point-source discharges (municipal wastewater discharges) probably are not a substantial source of phosphorus to surface water in the Cheney Reservoir watershed.

Historical (1965–98) percentages of phosphorus transported into Cheney Reservoir from natural and agricultural sources were calculated by Pope and others (2002) (fig. 2). These calculations were performed on the basis of a comparison between a mean concentration of phosphorus in soil from 43 nonagricultural coring sites, mostly cemeteries, in and near the Cheney Reservoir watershed (fig. 1) and a mean concentration of phosphorus in reservoir bottom sediment. Cemeteries were selected for soil sampling because they represent unique locations where soils have been protected from agricultural enrichment of phosphorus for extended periods. The comparison determined an agricultural-enrichment factor of 2.9 for phosphorus. This enrichment factor indicates that the phosphorus enrichment of watershed soil from agricultural activities has resulted in the transport of 2.9 times

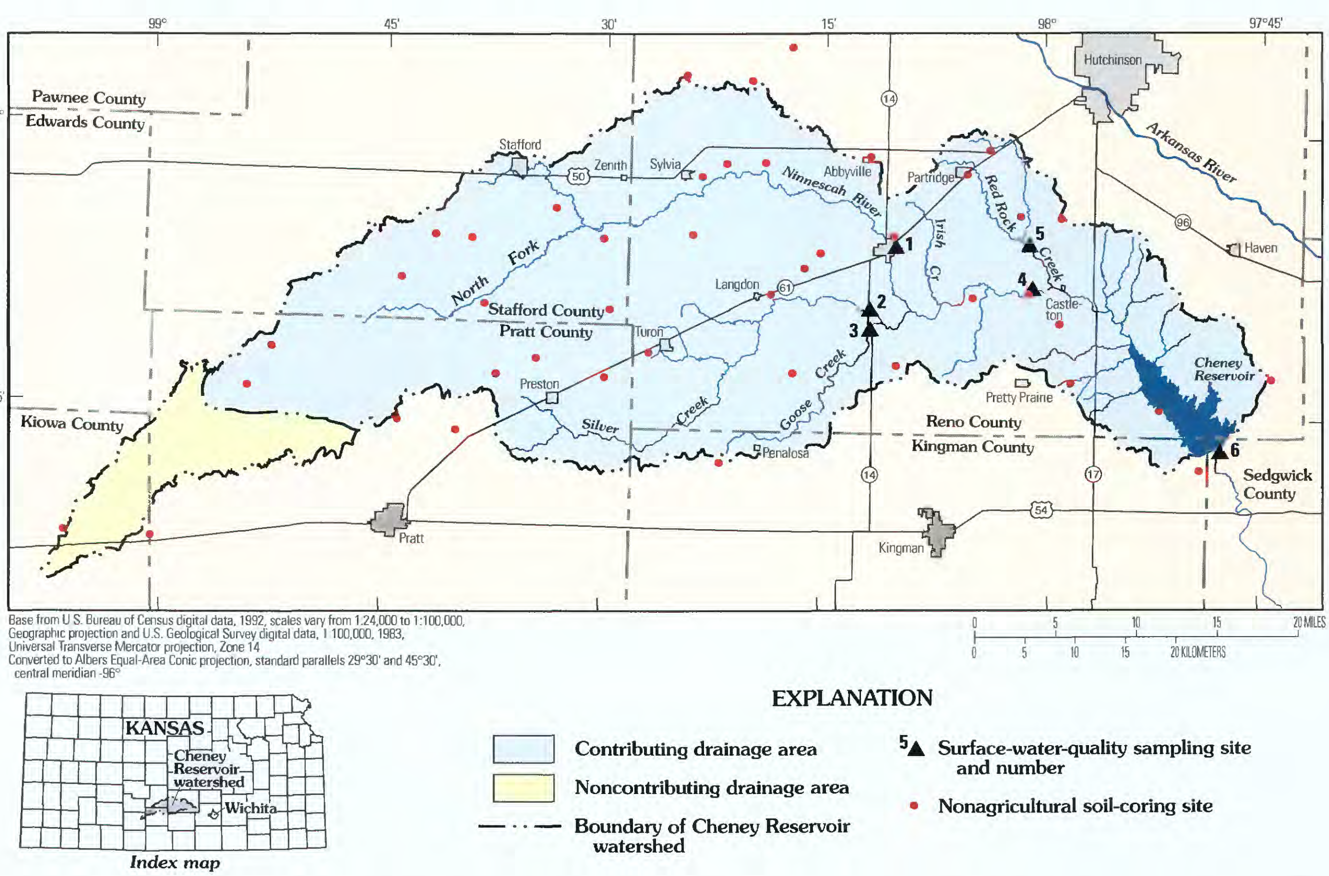

Figure 1. Location of Cheney Reservoir watershed, surface-water-quality sampling sites, and nonagricultural soil-coring sites, south-central Kansas.

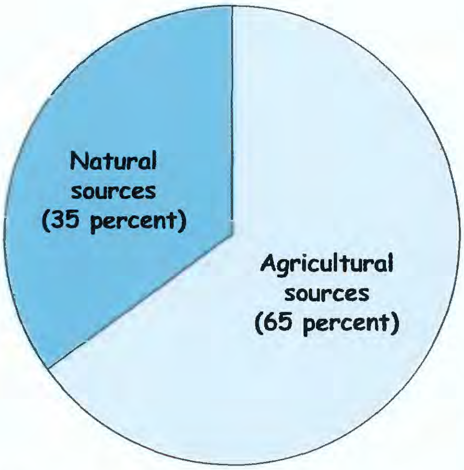

Figure 2. Percentages of phosphorus transported to Cheney Reservoir from natural and agricultural sources, 1965–98.

the amount of phosphorus to Cheney Reservoir than would have been expected under conditions where the watershed soil contained natural concentrations of phosphorus. Reference to phosphorus concentrations (soil or water) in this fact sheet denotes total phosphorus concentrations (suspended plus dissolved in the case of water).

Agricultural activities accounted for 65 percent of the phosphorus transported to Cheney Reservoir between 1965 and 1998 (fig. 2). This percentage is a historical average and may not accurately describe current (2001) conditions. However, this percentage does indicate that changes to agricultural or land-management practices that would mitigate the movement of phosphorus from agricultural fields or changes in phosphorus application and distribution in the watershed have a large potential for reducing the amount of phosphorus transported to Cheney Reservoir.

Concentrations of Phosphorus

Long-term (1997–2000) mean concentrations of phosphorus in water (fig. 3) were determined (Milligan and Pope, 2001) for the five surface-water-quality sampling sites upstream from Cheney Reservoir (fig. 1). These mean concentrations were calculated from the analyses of surface-water samples collected during base flow (low flow) and runoff (high flow) (table 1). On average, phosphorus concentrations were 2.0 (sampling site 2) to 4.4 (sampling sites 3 and 5) times larger in samples collected during runoff than in samples collected during base flow. Most phosphorus is transported to Cheney Reservoir during runoff. For example, at sampling site 4 (fig. 1), the main inflow site to Cheney Reservoir, it was estimated that 72 percent of the phosphorus in streamflow at this site during 1997–2000 was transported in runoff (Pope and others, 2002). This determination provides additional evidence that nonpoint sources (agricultural sources) are the main contributors of phosphorus in the Cheney Reservoir watershed.

Long-term (1997–2000) mean concentrations of phosphorus in water from the five sampling sites upstream from Cheney Reservoir (fig. 3) were 2.3 (sampling site 2) to 5.0 (sampling site 5) times larger than the 0.10-mg/L (milligram per liter) goal established by the Cheney Reservoir Watershed Task Force Committee (written commun., 1996). The 0.10-mg/L goal is the same as that recommended by the U.S. Environmental Protection Agency (1986) for limiting problems associated with nutrient enrichment of lakes and reservoirs.

The differences in long-term mean concentrations of phosphorus among the five sampling sites (fig. 3) probably is the result of a combination of natural and human-related factors. Natural factors may include differences in rainfall, topography, and soil characteristics such as texture (particle size), permeability, and erodibility. Human-related factors include land use, land management, and agricultural practices. Agricultural practices include the extent and magnitude of fertilizer applications and distribution of livestock manure. Little can be done to control the effects of the natural factors, but modifications to the human-related factors may reduce phosphorus inputs to the watershed and limit its movement to surface water.

To estimate how the watershed system might respond to reduced phosphorus inputs, the long-term (1997–2000) mean concentrations of phosphorus (fig. 3) were divided by the previously determined 2.9 agricultural-enrichment factor for phosphorus. This calculation, in effect, simulated (estimated) long-term mean phosphorus concentrations in the watershed under natural soil phosphorus conditions. Results of this simulation (fig. 3) indicated that even if soil in the watershed were maintained at natural concentrations of phosphorus, some streams (sampling sites 3 and 5) still would not meet the

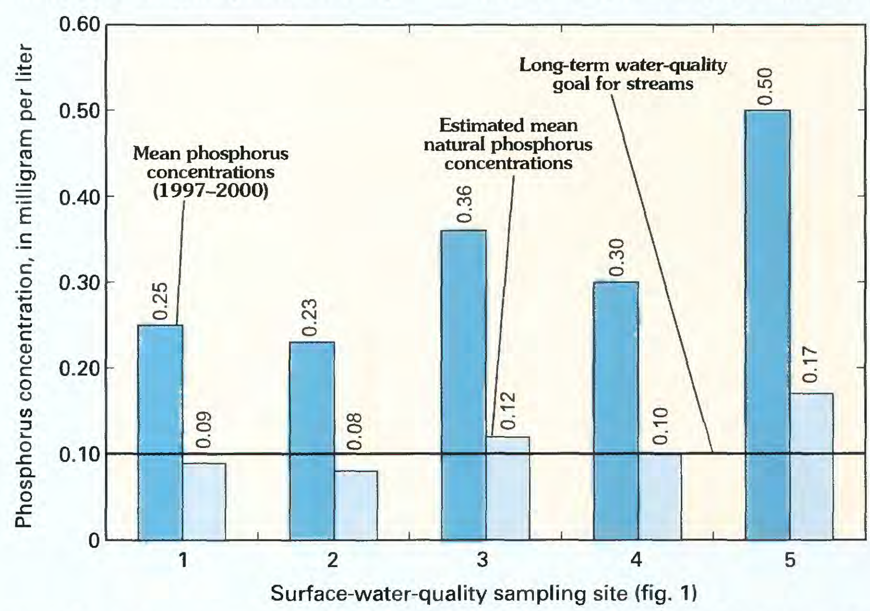

Figure 3. Comparison of mean phosphorus concentrations in water samples from five surface-water-quality sampling sites in Cheney Reservoir watershed to mean concentrations estimated on the basis of an agricultural-enrichment factor of 2.9. The long-term water-quality goal for phosphorus in streams was established by the Cheney Reservoir Watershed Task Force Committee (written commun., 1996).

Table 1. Number of samples analyzed and mean concentrations of total phosphorus in surface water during base-flow, runoff, and long-term streamflow conditions at sampling sites 1–5 in Cheney Reservoir watershed, south-central Kansas, 1997–2000

[Data from Milligan and Pope (2001). N, number of samples analyzed; mg/L, milligram per liter]

Sampling-site number (fig. 1)	Base flow		Runoff		Long term (1997–2000)	
	N	Mean concentration (mg/L)	N	Mean concentration (mg/L)	N	Mean concentration[1] (mg/L)
1	36	0.13	92	0.29	128	0.25
2	38	.14	78	.28	116	.23
3	40	.11	78	.48	118	.36
4	32	.10	85	.38	117	.30
5	37	.14	106	.62	143	.50

[1]Calculated using all available base-flow and runoff analyses.

water-quality goal of 0.10 mg/L. The implication of this finding is that reductions in the agricultural use of phosphorus alone may not provide the water-quality improvement necessary to meet the established phosphorus goal. Instead, it could involve a combination of approaches such as a reduction in use of phosphorus and more extensive implementation of land-management and agricultural practices to mitigate phosphorus loss from agricultural fields and movement to surface water.

Conclusions and Implications

Cheney Reservoir is a water-supply source for about 350,000 people in south-central Kansas and provides for downstream flood control, wildlife habitat, and recreational opportunities. As such, water quality in the reservoir is of great importance. The introduction of excessive amounts of phosphorus in the reservoir can degrade the water quality and result in treated drinking water that is aesthetically objectionable to consumers.

Agricultural activities in the Cheney Reservoir watershed have accounted for 65 percent of the phosphorus transported into Cheney Reservoir. Much of this phosphorus (72 percent) was transported by streams during runoff (high-flow) conditions. The positive implication of this large percentage of human-related phosphorus is that the possibility exists for substantial reductions in phosphorus to Cheney Reservoir through changes in human activities.

Long-term mean concentrations of phosphorus in water from five surface-water-quality sampling sites in the Cheney Reservoir watershed ranged from 0.23 to 0.50 mg/L, about two to five times the established water-quality goal for phosphorus. An estimation of mean concentrations of phosphorus at these sampling sites relative to the watershed with natural (nonagriculturally enriched) soil phosphorus conditions indicated that water from two of the five sampling sites still would not meet the water-quality goal for phosphorus. The implication of this finding is that reductions in the agricultural use or distribution of phosphorus alone may not be sufficient for some streams to meet the water-quality goal. Instead, it could involve a combination of approaches such as reducing phosphorus applications in the watershed and more extensive implementation of practices to inhibit phosphorus movement to streams.

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