Comparison of Sediment Deposition in Reservoirs of Four Kansas Watersheds

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Reservoirs are a vital source of water supply, provide recreational opportunities, support diverse aquatic habitat, and provide flood protection throughout Kansas. Understanding agricultural, industrial, and urban effects on reservoirs is important not only for maintaining acceptable water quality in the reservoirs but also for preventing adverse environmental effects. Excessive sediment can alter the aesthetic qualities of reservoirs and affect their water quality and useful life.

Introduction

Reservoir sediment studies are important because of the effect that sediment accumulation has on the quality of water and useful life of the reservoir. Sediment deposition can affect benthic organisms and alter the dynamics of the aquatic food chain. Reservoir sediment studies also are important in relation to watershed characteristics. For example, large volumes of sediment coming into reservoirs from agricultural areas can transport and deposit certain agricultural chemicals (such as phosphorus from fertilizer applications and some pesticides used in crop production) that are adsorbed to fine sediment particles (Juracek, 1997; Pope, 1998). Subsequently, these chemicals may be re-released into the water column and affect the drinking-water supply.

In the past, evaluations of sediment deposition in reservoirs have consisted of statistical analyses of historical data from sediment stations on tributaries flowing into the reservoirs and mapping of the reservoir bottom (bathymetric surveys). However, some reservoir watersheds in Kansas either lack or have an inadequate data base to use a statistical approach. Some data from surveys at selected cross sections (rangelines) prior to dam closure are available for reservoirs in Kansas completed by the U.S. Army Corps of Engineers (USACE) or the U.S. Department of the Interior's Bureau of Reclamation (BOR).

The U.S. Geological Survey (USGS) began studying reservoir sedimentation in Kansas in 1995. Nine reservoir studies have been carried out in cooperation with the Bureau of Reclamation, the city of Wichita, Johnson County Unified Wastewater Districts, the Kansas Department of Health and Environment, and (or) the Kansas Water Office. These studies were supported in part by the Kansas State Water Plan Fund and evaluated sediment deposition along with selected chemical constituents in sediment cores (fig. 1) from reservoirs located in various climatic, topographic, and geologic landscape regions throughout Kansas and southern Nebraska. Selected results from four of the reservoirs studied are summarized in this fact sheet—Webster Reservoir, Cheney Reservoir, Tuttle Creek Lake, and Hillsdale Lake (fig. 2). The four reservoirs were sampled between October 1, 1995, and September 30, 1999.

Figure 1. Bottom-sediment cores were collected with a gravity corer mounted on a pontoon boat. The corer is lowered to a designated distance above the sediment and allowed to free fall to penetrate through the entire thickness of reservoir bottom sediment.

This fact sheet describes:

- Total volume and rate of sediment deposition in each of the four reservoirs since impoundment;
- Possible causes for differences in total volume and rate of sediment deposition and the effects on water-storage capacity and useful life of the reservoir; and
- A baseline of sediment volume and mass with which results of future reservoir studies can be compared.

Reservoir and Watershed Characteristics

Reservoir and watershed characteristics vary among the four reservoirs (table 1). For example, long-term, mean annual precipitation ranges from about 24 inches at Webster Reservoir in north-central Kansas to about 41 inches at Hillsdale Lake (as measured 5 miles south at Paola in east-central Kansas) (National Oceanic and Atmospheric Administration, 1998). Contributing-drainage areas of the reservoirs also differed, ranging from 144 square miles for Hillsdale Lake to 9,600 square miles for Tuttle Creek Lake.

Land use in the Webster Reservoir watershed is primarily cropland (57 percent) and pastureland (37 percent) (Bureau of Reclamation, 1984, p. 9). The topography is flat to gently rolling, with narrow, shallow valleys and low relief. Despite their relatively high potential for erosion, soils in the Webster watershed are quite productive for small grain crops (Bureau of Reclamation, 1984, p. 6).

The Cheney Reservoir watershed is located in parts of five south-central Kansas counties. Land use is primarily agricultural, with about 52 percent of the watershed consisting of cropland and the balance (48 percent) consisting of pastureland, forest cover, or small urban areas. The topography is flat to gently rolling.

Tuttle Creek Lake has the largest contributing-drainage area and surface area of the four reservoirs. Approximately 75 percent of the contributing-drainage

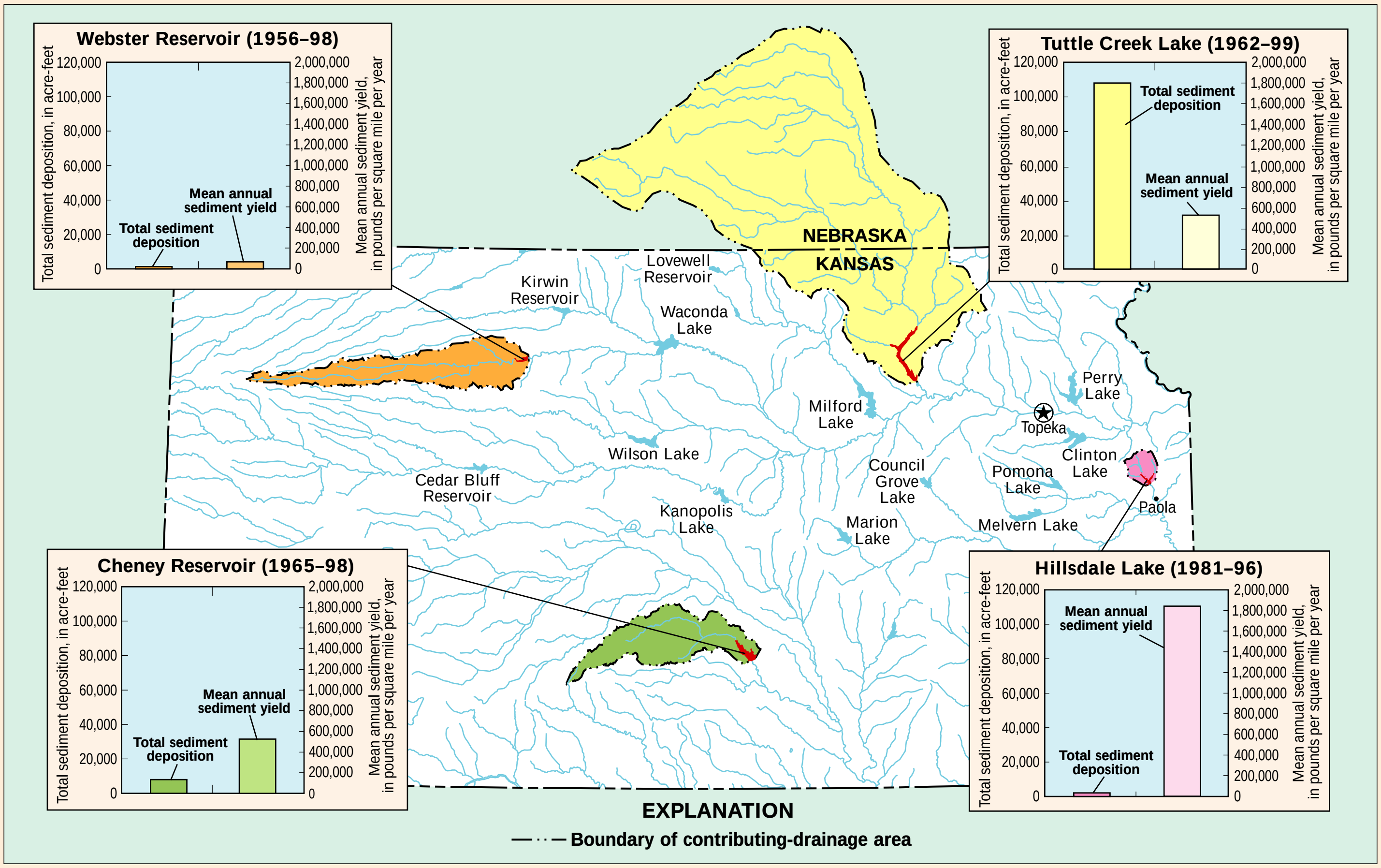

Figure 2. Volume of sediment deposited in four Kansas reservoirs and mean annual sediment yield from contributing-drainage areas vary as a result of differences in watershed precipitation, land use, topography, and geology.

area is located in southeast Nebraska and the remainder in northeast Kansas. About 72 percent of the drainage area is cropland, about 16 percent is pastureland, 10 percent is woodland, and the remainder is urban areas. The topography varies from smooth plains in the Nebraska section of the watershed to areas of greater local relief in the Kansas section of the watershed (Pope, 1995, p. 4).

The Hillsdale Lake watershed is located in parts of four northeast Kansas counties. Eighty-five percent of the land is cropland and pastureland, and the remaining 15 percent is used for feedlots and urban and residential development. Gently rolling uplands, with hilly areas along the streams, characterize the topography.

Methods

Bathymetric surveys were done at each reservoir along existing rangelines established by either the USACE or the BOR. Global positioning system (GPS) technology was used to record the geographic location of the boat on the reservoir, and a fathometer system was used to determine the depth to the top of the sediment. The data were digitally recorded and stored on a computer where additional processing was done to compare the original pre-reservoir rangeline data to the most recent bathymetric data.

The total volume and rate of sediment deposition in all four reservoirs were determined by a comparison of the recent (1995–99) reservoir bottom elevation to the elevation prior to impoundment. The difference in elevations between the two periods is primarily the result of sediment deposition. Storm runoff transports large amounts of sediment into reservoirs causing temporal variability in the rates of sediment deposition. Because bathymetric surveys have been done infrequently throughout the life of the four reservoirs, it

Table 1. Comparison of reservoir and watershed characteristics for Webster Reservoir, Cheney Reservoir, Tuttle Creek Lake, and Hillsdale Lake

[<, less than]

Reservoir or lake	Date of impoundment	Contributing-drainage area (square miles)	Original conservation pool storage[1] (acre-feet)	Land use[2]: Percentage of basin in pastureland	Land use[2]: Percentage of basin in cropland	Long-term mean annual precipitation[3] (inches)
Webster	1956	1,150	72,000	37	57	24
Cheney	1965	933	152,000	<48	52	27
Tuttle Creek	1962	9,600	425,000	16	72	32
Hillsdale	1981	144	68,000	50	35	41

[1]Conservation pool storage data for Webster Reservoir from Ferrari (1997), for Cheney Reservoir from Putnam and others (1999), for Tuttle Creek Lake from U.S. Army Corps of Engineers (written commun., 1999) and for Hillsdale Lake from Juracek (1997).

[2] Land-use percentages from Nebraska Natural Resources Commission (1983), Bureau of Reclamation (1984), Kansas Geological Survey (1993), Kansas Department of Agriculture and U.S. Department of Agriculture (1997), and Putnam (1997).

[3] Long-term mean annual precipitation is based on 1961–90 data from the National Oceanic and Atmospheric Administration (1998).

was not feasible to calculate annual volumes and rates of sediment deposition. Therefore, a mean annual deposition rate for each reservoir was estimated by dividing the total accumulated sediment volume by the number of years since reservoir impoundment. Mean annual sediment yield was estimated by dividing the mean annual deposition rate by watershed area in square miles.

Dry-mass estimates of sediment deposition to the reservoirs required determining reservoir bottom-sediment bulk density. This was done by collecting reservoir bottom sediment using a gravity corer (fig. 1). Sediment cores were collected from several locations in the reservoirs to define sedimentation variability. The core samples were processed at the USGS laboratory in Lawrence, Kansas, and analyzed for percentage of sand and silt and (or) clay, bulk density, and percentage of moisture, according to methods presented in Guy (1969).

Comparison of Reservoir Sediment Deposition

Large differences in total sediment deposition volume are apparent between the four reservoirs (fig. 2). Total sediment deposition estimates ranged from 1,330 acre-feet at Webster Reservoir to 114,000 acre-feet at Tuttle Creek Lake. However, when differences in reservoir contributing-drainage area and age of the reservoir were accounted for, mean annual sediment deposition, in acre-feet per square mile of contributing-drainage area, was actually largest at Hillsdale Lake (0.93 acre-feet per square mile) followed by Tuttle Creek Lake (0.31 acre-feet per square mile) and Cheney Reservoir (0.25 acre-feet per square mile). Webster Reservoir had the smallest mean annual sediment deposition per square mile of contributing-drainage area (0.03 acre-feet per square mile). When the mass of reservoir sediment was determined using reservoir sediment-volume and bulk-density data, there were also large differences. Mean annual sediment yields (fig. 2) were smallest from the Webster Reservoir watershed (68,100 pounds per square mile per year) and largest from the Hillsdale Lake watershed (1,840,000 pounds per square mile per year).

The four reservoirs provide drinking-water supplies for many local communities, as well as water for irrigating cropland. Sediment deposition reduces storage volume and the useful life of a reservoir. An evaluation of sediment deposition for each reservoir described in this fact sheet showed that deposition was less than would be expected on the basis of the 100-year reservoir-design life historically used by Federal agencies. Accordingly, reservoir water-storage volumes estimated at the time of each reservoir study were greater than the calculated reservoir-design storage volumes.

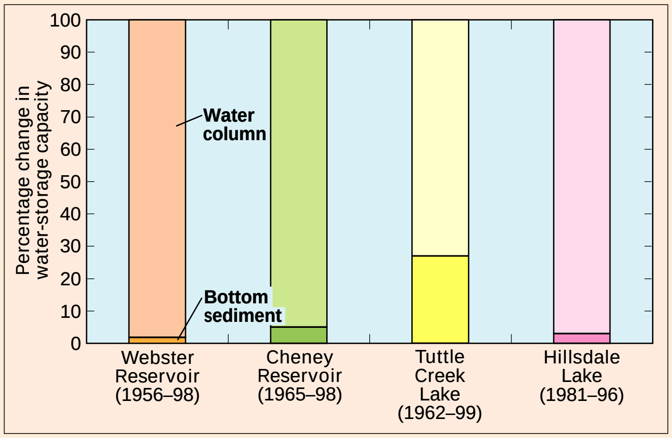

Figure 3. Sediment deposition has caused almost a 27-percent decrease in water-storage capacity in Tuttle Creek Lake, whereas decreases in water-storage capacities in Webster Reservoir, Cheney Reservoir, and Hillsdale Lake were 5 percent or less.

A decline in water supply can have serious ramifications for the users of that supply. On the basis of bathymetric surveys and analysis of reservoir bottom-sediment cores, the calculated water-storage capacities in the four reservoirs declined from less than 2 percent at Webster Reservoir to about 27 percent at Tuttle Creek Lake (fig. 3).

Several possible reasons exist for differences in total volumes and rates of sediment deposition among the four reservoirs. Because precipitation contributes to streamflow and ultimately the transport of suspended sediment into the reservoir under certain conditions, larger volumes of sediment more likely would be deposited in reservoirs having watersheds that receive more precipitation. On the basis of data for the four reservoirs described in this fact sheet, sediment deposition increases as precipitation increases (fig. 4).

However, precipitation alone does not account for all the differences in sediment deposition. Other variables such as land use, topography, soil types, geology, and contributing-drainage area, are also important in the evaluation of sediment transport. The Hillsdale Lake watershed, for instance, may be more prone to erosion losses on a per-square-mile basis when large amounts of annual precipitation are combined with the large percentage of cropland, rolling topography, and an increase in urbanization. The Webster Reservoir watershed has significantly less precipitation than the Hillsdale Lake watershed and a more gently sloping topography. Erosion losses would be expected to be less in that type of environment. Also, more than 800 small farm ponds in the Webster Reservoir watershed act as water and sediment traps, reducing the peak streamflows and volume of suspended sediment transported into the reservoir (Bureau of Reclamation, 1984, p. 37). Small watershed impoundments may have a substantial effect on the transport of sediment to the other reservoirs as well.

In contrast, differences in mean annual sediment yield on a per-square-mile basis between Cheney Reservoir and Tuttle Creek Lake watersheds were within about 20 percent of each other. The generally flat to gently sloping topography of the Cheney Reservoir watershed in combination with less precipitation and soils classified as sand or sandy loam in the lowland areas contrasts with the more variable topography of the Tuttle Creek watershed. Maximum relief of 300 to 500 feet occurs in the Tuttle Creek

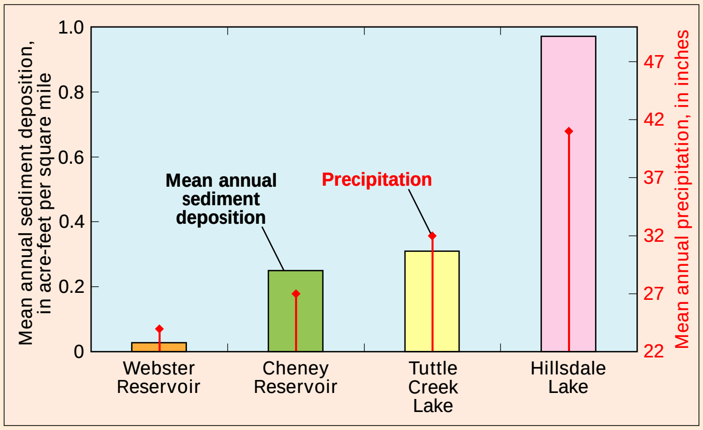

Figure 4. A direct relation is apparent between mean annual sediment deposition and long-term, mean annual precipitation at Webster Reservoir, Cheney Reservoir, Tuttle Creek Lake, and Hillsdale Lake. Long-term, mean annual precipitation is based on 1961–90 data from the National Oceanic and Atmospheric Administration (1998).

Tuttle Creek Lake looking north from east side of Randolph Bridge showing sediment accumulation (photograph by Michael Kemppainen, USGS, Lawrence, Kansas).

watershed near the reservoir, the tributary drainage channels are well incised, and the soils are of glacial till origin, consisting of silt, clay, sand, and gravel. However, mean annual precipitation in the Cheney Reservoir and Tuttle Creek Lake watersheds (27 and 32 inches, respectively) are similar, and land use in both watersheds is primarily agricultural, with more than 50 percent of each watershed being cropland.

Conclusions and Implications

Webster Reservoir, Cheney Reservoir, Tuttle Creek Lake, and Hillsdale Lake showed large differences in total sediment deposition estimates, ranging from 1,330 acre-feet in Webster Reservoir to 114,000 acre-feet in Tuttle Creek Lake. However, the Hillsdale Lake watershed had the largest mean annual sediment yield and exceeded the next largest, the Tuttle Creek Lake watershed, by a factor of three. Water-storage capacity decreased by about 27 percent in Tuttle Creek Lake and 5 percent or less in Webster Reservoir, Cheney Reservoir, and Hillsdale Lake.

Long-term, mean annual precipitation in Kansas decreases from east to west, from about 41 inches at Hillsdale Lake to 24 inches at Webster Reservoir. Mean annual sediment deposition volume in reservoirs per square mile of contributing-drainage area showed a direct relation to long-term, mean annual precipitation at the reservoirs. However, other factors that are not as easily quantified are probably important contributors to the rate of sediment deposition. These factors include land use, topography, soil type, geology, and the effects of small water impoundments.

Chemicals that adsorb to fine sediment particles, such as phosphorus from fertilizer application and some pesticides used in crop production, can be transported to reservoirs and stored in reservoir-bottom sediment. The percentage of land in the contributing-drainage area used for cropland and the associated use of fertilizers and pesticides also affect the concentration and mass of pesticides in reservoir bottom sediment. These chemicals may pose a risk to the drinking-water supply or the aquatic community. To reduce the transport of sediment and chemicals into reservoirs and to maintain the water quality, land-resource best-management practices (BMP's) have been implemented in several Kansas watersheds. Some examples include riparian buffer zones near tributary streams and creeks, no-till farming in lowland areas, land terracing where appropriate, and reduction of cropland in areas where sediment erosion is extensive.

The reservoir sediment studies in Kansas have shown how bathymetric surveying and reservoir-sediment coring can be combined to determine volume and rates of sediment deposition in each reservoir and to establish a baseline of sediment volume and mass with which to evaluate future reservoir data. Changes in water-storage capacities also may be determined, which is a concern for sustaining the reservoirs as water-supply sources. Additionally, water-resource managers in the watersheds can use this information and information on the chemical composition of the sediment to evaluate the effectiveness of implemented BMP's so that action may be taken to preserve the aesthetic and chemical quality and to lengthen the useful life of the reservoirs.

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For more information on reservoir sediment studies in Kansas, visit the USGS Web site at:
http://ks.water.usgs.gov/Kansas/ressed/
or contact:

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