EFFECTS OF NONAGRICULTURAL HUMAN ACTIVITY ON SEDIMENT QUALITY: A COMPARISON OF TRACE ELEMENT CONCENTRATIONS IN EIGHT SMALL RESERVOIRS

Kyle Juracek, Research Hydrologist, U.S. Geological Survey, Lawrence, Kansas, kjuracek@usgs.gov; Andrew Ziegler, Supervisory Hydrologist, U.S. Geological Survey, Lawrence, Kansas, aziegler@usgs.gov

INTRODUCTION

Small reservoirs are valued by the general public both as a source of drinking water and for recreational activities. In addition to information on water quality and sedimentation, effective reservoir management requires information on sediment quality. Sediment quality is an important environmental concern because sediment may act as a sink for some water-quality constituents and, under certain conditions, as a source of constituents to the overlying water column and biota (Baudo et al., 1990; Zoumis et al., 2001). Once in the food chain, sediment-derived constituents may pose an even greater concern because of bioaccumulation. An analysis of reservoir bottom sediments can provide historical information on sediment deposition as well as the occurrence of sediment-bound constituents. Such information may be used to partly reconstruct historical sediment-quality and water-quality records and to determine a present-day baseline with which to evaluate long-term changes in reservoir sediment and water quality that may be related to changes in human activity in the contributing basin (Charles and Hites, 1987; Van Metre and Callender, 1996; Van Metre and Mahler, 2004). Moreover, such information may be used to assist in the development, implementation, evaluation, and revision of total maximum daily loads (TMDLs) for sediment and associated constituents that contribute to the water-quality impairment of reservoirs.

To investigate the effects of nonagricultural human activity on sediment quality, sediment cores were collected from eight small reservoirs in eastern Kansas with basins of diverse land-use combinations. The sediment samples were analyzed for selected trace elements. Most, if not all, trace elements may be toxic in animals and humans if the concentrations are sufficiently large (Pais and Jones, 1997). Specific study objectives were to: (1) determine the occurrence and trends of trace elements in the reservoir bottom sediments, (2) assess sediment quality with respect to available guidelines, and (3) interpret the effects of nonagricultural human activity (in the basin or the reservoir) on sediment quality within and among the eight reservoirs.

The eight small reservoirs selected for the study were Bronson City Lake, Centralia Lake, Crystal Lake, Gardner City Lake, Lake Afton, Mission Lake, Otis Creek Reservoir, and Pony Creek Lake. The locations of the reservoirs are provided in Juracek (2004). Each of these reservoirs is used as a public water supply and (or) for recreation. All but Otis Creek Reservoir were listed under Section 303(d) of the Federal Clean Water Act of 1972 for eutrophication. The 303(d) list is a priority list that identifies water bodies that do not meet water-quality standards on the basis of the use of the water bodies. For each impaired water body on the 303(d) list, a State is required by the Clean Water Act to develop a TMDL, which is an estimate of the maximum pollutant load (material transported during a specified time period) from point and nonpoint sources that a receiving water can accept without exceeding water-quality standards (U.S. Environmental Protection Agency, 1991). Otis Creek Reservoir, which was not on the 303(d) list, was included in the study for the purpose of comparison.

Description of Reservoir Basins: The small reservoirs included in this study have completion dates ranging from 1879 (Crystal Lake) to 1993 (Pony Creek Lake). The reservoir basins range in area from less than 1 mi^2 (Bronson City Lake, Crystal Lake) to 14.0 mi^2 (Otis Creek Reservoir). The original water-storage capacities for the reservoirs range from 229 acre-ft (Crystal Lake) to 5,845 acre-ft (Otis Creek Reservoir). Available information indicated that the reservoirs have not been dredged. Table 1 provides the year completed, approximate basin area, and original water-storage capacity for each of the small reservoirs.

Long-term mean annual precipitation ranges from about 30 in. for the Lake Afton Basin to about 40 in. for the Bronson City Lake and Crystal Lake Basins (High Plains Regional Climate Center, 2002). Most of the annual precipitation is received during the growing season (generally April–September).

Table 1. Year completed, approximate basin area, original water-storage capacity, and number of sediment-core intervals analyzed for eight small reservoirs in eastern Kansas.[mi^2, square miles; --, not available]

Reservoir	Year completed	Approximate basin area (mi^2)	Original water-storage capacity[1] (acre-feet)	Number of sediment-core intervals analyzed
Bronson City Lake	1956	0.8	--	3
Centralia Lake	1990	12.5	4,769	3
Crystal Lake	1879	.6	229	10
Gardner City Lake	1940	5.5	2,301	5
Lake Afton	1942	10.4	3,264	5
Mission Lake	1924	8.6	1,866	5
Otis Creek Reservoir	1971	14.0	5,845	5
Pony Creek Lake	1993	6.6	2,367	3

[1]Sources of information for original water-storage capacity provided in Juracek (2004).

Land use (1988–90) in the basins is a mostly agricultural mix of cropland and grassland. Cropland is the dominant land use in the Bronson City Lake, Centralia Lake, Lake Afton, Mission Lake, and Pony Creek Lake Basins. Grassland is the dominant land use in the Crystal Lake and Otis Creek Reservoir Basins. The Gardner City Lake Basin is characterized by a mix of cropland, grassland, and urban land uses. Substantial urban land use also is present in the Crystal Lake Basin (Kansas Applied Remote Sensing Program, 1993).

Acknowledgments: This study was made possible in part by support from the U.S. Geological Survey (USGS) Cooperative Water Program, the Kansas State Water Plan Fund, the Kansas Department of Health and Environment, the U.S. Environmental Protection Agency (USEPA), the U.S. Department of Agriculture’s Natural Resources Conservation Service, and the Fall River Watershed Joint District No. 21.

METHODS

Sediment-Core Collection, Sampling, and Analysis: The objectives of this study were accomplished through the collection and analysis of one bottom-sediment core from each of the eight reservoirs. The cores were collected in 2002 and 2003. Typically, each core was collected (using a gravity corer) from a site located in the downstream one-third of the reservoir relatively close to the dam. The near-dam site was selected because it is in relatively deep water where the sediment was least likely to be disturbed.

The number of intervals sampled for trace element analyses for each core ranged from 3 to 10 (table 1) and was dependent on reservoir age and sediment thickness. Samples were analyzed for arsenic, cadmium, chromium, copper, lead, nickel, and zinc. Elevated concentrations of these trace elements frequently are indicative of human activity. For example, elevated copper concentrations often reflect the historical application of copper sulfate to control algal blooms. Elevated lead concentrations often are indicative of the historical use of leaded gasoline. Trace element analyses were performed at the USGS Sediment Trace Element Partitioning Laboratory in Atlanta, Georgia, using the methods described by Fishman and Friedman (1989), Arbogast (1996), and Briggs and Meier (1999). Age dating of the bottom sediment in some cores was accomplished by determining the activity of cesium-137 (^{137}Cs) by gamma-ray spectrometry (American Society for Testing and Materials, 2000).

Sediment-Quality Assessment: MacDonald et al. (2000) developed consensus-based, sediment-quality guidelines (SQGs) that were computed as the geometric mean of several previously published SQGs. The consensus-based SQGs consist of a threshold effect concentration (TEC) and a probable effect concentration (PEC). The TEC represents the concentration below which harmful effects on sediment-dwelling organisms are not expected to occur, whereas the PEC represents the concentration above which harmful effects on sediment-dwelling organisms are expected to occur frequently. Generally, these guidelines are similar to USEPA adopted nonregulatory SQGs for threshold effects levels (TELs) and probable effects levels (PELs) (U.S. Environmental Protection Agency, 1997). An evaluation of the reliability of the consensus-based SQGs indicated that most of the individual TECs and PECs provide an accurate basis for predicting the presence or absence of sediment toxicity (MacDonald et al., 2000). The TECs and PECs for the seven trace elements analyzed in this study are provided in table 2.

To provide a comparative assessment of the reservoirs in terms of the effects of nonagricultural human activity on sediment quality over the life of the reservoirs, two measures were used. First, the median concentration was determined for each trace element. Second, the percentage of samples that exceeded the TEC for each trace element was computed.

Table 2. Consensus-based sediment-quality guidelines, median trace element concentrations, and percentage of samples that exceeded the threshold effect concentration for eight small reservoirs in eastern Kansas.[As, arsenic; Cd, cadmium; Cr, chromium; Cu, copper; Pb, lead; Ni, nickel; Zn, zinc; TEC, threshold effect concentration; PEC, probable effect concentration; µg/g, micrograms per gram; --, not applicable]

Consensus-based sediment-quality guideline[1]/ reservoir	**Trace element**						
	As	**Cd**	**Cr**	**Cu**	**Pb**	**Ni**	**Zn**
TEC, µg/g	9.79	0.99	43.4	31.6	35.8	22.7	121
PEC, µg/g	33.0	4.98	111	149	128	48.6	459
Median concentration (µg/g) and percentage of samples that exceeded the TEC in parentheses ( )							
Bronson City Lake	15(100)	0.7(33)	74(100)	200(100)	34(33)	37(100)	150(100)
Centralia Lake	18(100)	.8(0)	77(100)	30(0)	19(0)	40(100)	110(0)
Crystal Lake	17(100)	.9(30)	79(100)	122(60)	49(70)	38(100)	220(100)
Gardner City Lake	18(100)	.6(0)	87(100)	77(100)	42(100)	43(100)	160(100)
Lake Afton	12(100)	.7(0)	71(100)	33(100)	45(80)	38(100)	130(60)
Mission Lake	15(100)	.3(0)	83(100)	32(60)	29(0)	41(100)	140(60)
Otis Creek Reservoir	11(100)	.5(0)	78(100)	21(0)	23(0)	36(100)	67(0)
Pony Creek Lake	14(100)	.5(0)	72(100)	26(0)	25(0)	37(100)	110(0)

[1]MacDonald et al. (2000).

RESULTS AND DISCUSSION

Bronson City Lake: In the bottom sediment of Bronson City Lake, arsenic, chromium, nickel, and zinc concentrations all exceeded the TECs but were less than the PECs. Cadmium and lead concentrations were either slightly greater than or slightly less than the respective TECs. Copper concentrations exceeded the PEC. The elevated concentrations of copper likely are due to the historical application of copper sulfate to control algal blooms in the reservoir (Ellen Harper, city of Bronson, oral commun., 2003). With the exception of a possible negative trend for lead, no trends in trace element concentrations were evident in the core samples.

Centralia Lake: Arsenic, chromium, and nickel concentrations in the bottom sediment of Centralia Lake all exceeded the TECs but were less than the PECs. All cadmium, copper, lead, and zinc concentrations were less than the TECs. No trends in trace element concentrations were indicated.

Crystal Lake: In the bottom sediment of Crystal Lake, arsenic, chromium, and zinc concentrations all exceeded the TECs but were less than the PECs. Most of the cadmium concentrations were less than the TEC. Copper concentrations ranged from less than the TEC for the bottom (oldest) four core intervals to larger than the PEC for the top (most-recent) five intervals (fig. 1*A*). With the exception of the bottom (oldest) three intervals, which were less than the TEC, lead concentrations exceeded the TEC but were less than the PEC. All nickel concentrations exceeded the TEC but were less than the PEC.

Trend analyses, with a significance level of 0.05, indicated a statistically significant positive trend (constituent concentration increased toward the top of the sediment core) for copper (fig. 1*A*), lead (fig. 1*B*), and zinc (fig. 1*C*).

Because the ^{137}Cs activity has a well-defined 1963–64 peak followed by a uniform, exponential decrease (fig. 1*D*), it was concluded that the bottom sediment in Crystal Lake is relatively undisturbed, and the trends may be considered representative of historical deposition. The indicated positive trends for copper, lead, and zinc do not appear to be caused by analytical variance as the majority of the concentrations were not within 10 percent of the mean concentration.

The indicated positive trends may be due to human activity in and near the Crystal Lake Basin. The elevated concentrations of copper in the upper one-half of the sediment core (fig. 1*A*) likely were caused by the historical application of copper sulfate (beginning in the 1940s or 1950s) to control algal blooms in the reservoir (Rick Doran, city of Garnett, oral commun., 2003). Increased concentrations of zinc (fig. 1*C*) may be attributed to increased vehicular traffic and associated tire wear over time (Callender and Rice, 2000).

For lead, there was a statistically significant positive trend over the life of the reservoir. However, inspection of figure 1*B* indicates that the initial positive trend leveled off and became a negative trend at the top of the core. This profile is consistent with the history of particulate lead emissions from leaded gasoline use in the United States. Leaded gasoline was introduced in the 1920s and quickly became standard (Davies, 1990). Use of leaded gasoline increased until its phase out, legislated by the Clean Air Act of 1970, began in the 1970s. From 1970 to 1990, total national lead emissions from vehicles decreased an estimated 99.8 percent (U.S. Environmental Protection Agency, 2000). Results indicated that, following the phase out of leaded gasoline, it will take at least several decades for lead in newly deposited reservoir bottom sediments to return to historical baseline concentrations.

Because Crystal Lake was completed in 1879, the trace element concentrations at the bottom of the sediment core likely provide an indication of historical baseline concentrations. Evidence in support of this interpretation is provided by the substantially smaller and relatively uniform concentrations of lead and zinc in the bottom three core intervals (figs. 1*B* and 1*C*).

For arsenic, chromium, nickel, and zinc, the historical baseline concentrations (likely represented by the bottom three core intervals) are substantially larger than the respective TECs (Juracek, 2004). This finding indicates that, for certain trace elements in certain areas, historical baseline concentrations may exceed the TECs prior to the effects of substantial nonagricultural human activity in the basin.

Gardner City Lake: Arsenic, chromium, lead, nickel, and zinc concentrations in the bottom sediment of Gardner City Lake all exceeded the TECs but were less than the PECs. Cadmium concentrations were less than the TEC.

All copper concentrations exceeded the TEC, and the top (most-recent) interval of the core had a concentration that also exceeded the PEC. Throughout the life of the reservoir, a positive trend in copper concentrations is evident in the bottom sediment. The positive trend is likely caused by frequent applications of copper sulfate (since the 1970s) to control algal blooms in the reservoir (Mike Howard, city of Gardner, written commun., 2003). The concentration profile for lead is consistent with the history of particulate lead emissions from leaded gasoline use in the United States. Because the ^{137}Cs activity has a well-defined 1963–64 peak followed by a uniform, exponential decrease (Juracek, 2004), it was concluded that the bottom sediment in Gardner City Lake is relatively undisturbed, and the trends may be considered representative of historical deposition.

Lake Afton: In the bottom sediment of Lake Afton, arsenic, chromium, copper, and nickel concentrations all exceeded the TECs but were less than the PECs. Cadmium concentrations were less than the TEC. Zinc concentrations were either slightly less than or larger than the TEC (but less than the PEC). For lead, four of five concentrations exceeded the TEC but were less than the PEC. The concentration profile for lead is consistent with the history of particulate lead emissions from leaded gasoline use in the United States. Because the ^{137}Cs activity has a well-defined 1963–64 peak followed by a uniform, exponential decrease (Juracek, 2004), it was concluded that the bottom sediment in Lake Afton is relatively undisturbed and the concentration profile for lead is representative of historical deposition.

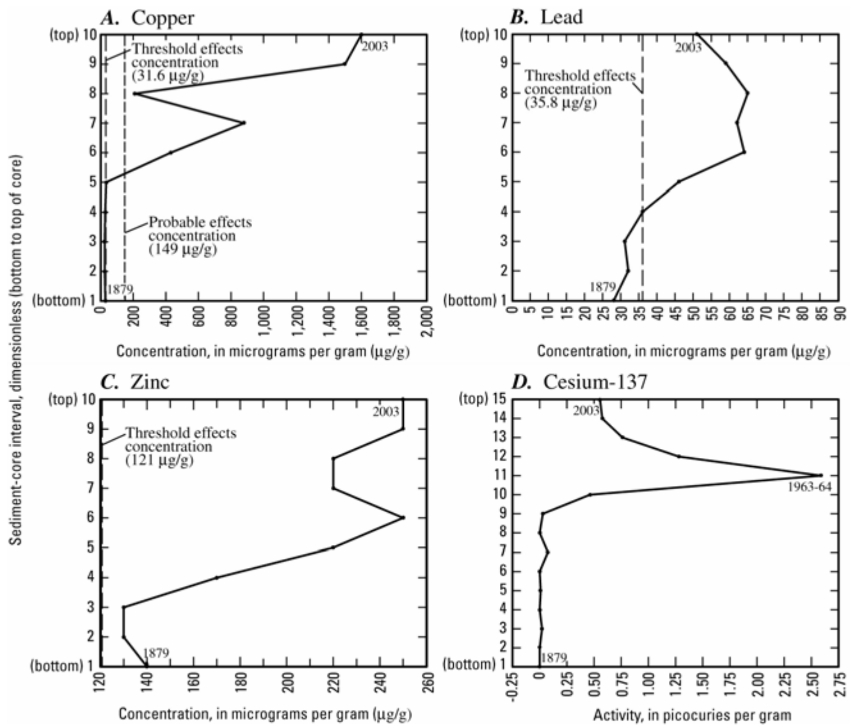

Figure 1. Variation in (A) copper concentrations, (B) lead concentrations, (C) zinc concentrations, and (D) cesium-137 activity with depth of bottom-sediment core samples collected from Crystal Lake, April 2003. Threshold and probable effect concentrations from MacDonald et al. (2000).

Mission Lake: Arsenic, chromium, and nickel concentrations in the bottom sediment of Mission Lake all exceeded the TECs but were less than the PECs. Copper concentrations were either slightly less than or slightly greater than the TEC. For lead, all concentrations were less than the TEC. The concentration profile for lead subtly reflects the history of particulate lead emissions associated with the use of leaded gasoline in the United States. For zinc, the two oldest intervals had concentrations that were slightly less than the TEC, whereas the remaining intervals had concentrations that exceeded the TEC but were less than the PEC. All cadmium concentrations were less than the TEC.

Otis Creek Reservoir: In the bottom sediment of Otis Creek Reservoir, arsenic, chromium, and nickel concentrations all exceeded the TECs but were less than the PECs. For cadmium, copper, lead, and zinc, all concentrations were less than the TECs. No trends for trace elements were indicated in the core.

Pony Creek Lake: Arsenic, chromium, and nickel concentrations in the bottom sediment of Pony Creek Lake all exceeded the TECs but were less than the PECs. All cadmium, copper, lead, and zinc concentrations were less than the TECs. No trends for trace elements were evident in the core.

Interlake Comparison: The eight small reservoirs were compared in terms of median trace element concentrations. Additionally, the reservoirs were compared using the percentage of samples that exceeded the TEC for each trace element.

Considered with respect to the SQGs, a comparison of the median trace element concentrations indicated that the eight reservoirs were similar in terms of arsenic, cadmium, chromium, and nickel concentrations (table 2). For arsenic, chromium, and nickel, every sediment sample for every reservoir had concentrations that exceeded the TECs but were less than the PECs. For cadmium, the sediment concentrations were typically less than the TEC. The generally similar concentrations and lack of trends over time (Juracek, 2004) may be indicative of a relative absence of effects of nonagricultural human activity on sediment quality for these four trace elements.

The effects of nonagricultural human activity on sediment quality were pronounced for copper, lead, and zinc. For copper, the effects of copper sulfate application were evident for Bronson City, Crystal, and Gardner City Lakes. Median copper concentrations for Bronson City and Crystal Lakes were substantially larger than for the other reservoirs (table 2). For these two reservoirs, at least one-half of the copper concentrations exceeded the PEC.

The history of leaded gasoline use apparently was documented by lead deposition in the bottom sediment of Crystal Lake (fig. 1*B*), Gardner City Lake, Lake Afton, and, to a lesser degree, Mission Lake (Juracek, 2004). That is, the reversal from an initial positive trend to a negative trend reflects the historical increase in consumption of leaded gasoline from the 1920s until the late 1970s when the phase out of lead from gasoline began (Callender and Van Metre, 1997; Callender and Rice, 2000). The fact that the largest median lead concentration was measured in the bottom sediment of Crystal Lake likely is because of the presence of the well-traveled U.S. Highway 59, which is located within the Crystal Lake Basin less than 100 ft upstream from the reservoir shore. In contrast, lead deposition in the bottom sediment of Otis Creek Reservoir was uniform through time with relatively small concentrations (Juracek, 2004). The lack of trend at this location may be attributable to the remote location of the Otis Creek Reservoir Basin, which is several miles from the nearest highway in every direction.

The variability of zinc concentrations in the bottom sediment of the reservoirs also likely was affected by human activity. A significant source of zinc is vehicular tire wear. Callender and Rice (2000) determined that increased zinc concentrations in sediment are related to increased vehicular traffic. The fact that the largest median zinc concentration was measured in the bottom sediment from Crystal Lake likely was because of its proximity to U.S. Highway 59. The fact that the smallest median zinc concentration was measured in the bottom sediment from Otis Creek Reservoir likely was because of the relative absence of vehicular traffic in and near its basin.

A comparison of the reservoirs in terms of the relative concentrations of trace elements in the bottom sediment also indicated effects of nonagricultural human activity. Typically, Crystal Lake and Gardner City Lake were among the reservoirs with the largest median sediment concentrations for the seven trace elements considered (table 2). Crystal Lake had the largest median concentrations for cadmium, lead, and zinc. Gardner City Lake had the largest median concentrations for arsenic (along with Centralia Lake) and chromium. Crystal Lake and Gardner City Lake are the only two reservoirs with a substantial percentage of urban land use in their basins.

Otis Creek Reservoir was included in this study for the purpose of comparison. Because of its relatively remote location and the fact that land use in its basin is almost exclusively grassland, Otis Creek Reservoir provided an opportunity to assess effects of nonagricultural human activity on the deposition of trace elements in the bottom sediment of the other reservoirs. For arsenic, cadmium, copper, lead, and zinc, the bottom-sediment concentrations in samples from Otis Creek Reservoir typically were the smallest or among the smallest measured. For chromium and nickel, the bottom-sediment concentrations in samples from Otis Creek Reservoir generally were comparable to samples from the other reservoirs (Juracek, 2004) (table 2).

A comparison of the overall effects of nonagricultural human activity on sediment quality over the life of the reservoirs, evaluated using the percentage of samples that exceeded the TEC for each of the seven trace elements, indicated that Bronson City Lake, Crystal Lake, Gardner City Lake, and Lake Afton were the most affected. Primary factors that contributed to increased trace element deposition in these reservoirs included vehicular traffic in the basins and copper sulfate application in the reservoirs. Urban land use likely was an additional contributing factor in the Crystal Lake and Gardner City Lake Basins. Among the remaining reservoirs, results indicated that the effects of nonagricultural human activity on trace element deposition were relatively moderate for Mission Lake and relatively minimal for Centralia Lake, Otis Creek Reservoir, and Pony Creek Lake (table 2).

SUMMARY AND CONCLUSIONS

To investigate the effects of nonagricultural human activity on sediment quality, sediment cores were collected from eight small reservoirs in eastern Kansas with basins of diverse land-use combinations. Samples from the sediment cores were analyzed for arsenic, cadmium, chromium, copper, lead, nickel, and zinc to assess changes in trace element deposition over the life of the reservoirs.

Results indicated that sediment concentrations of arsenic, cadmium, chromium, and nickel were similar among reservoirs and over time. Because the level of nonagricultural human activity in the eight basins varies considerably, its effects on the deposition of these four trace elements in the reservoirs were interpreted to be minimal. Substantial differences among the reservoirs were indicated for the sediment concentrations of copper, lead, and zinc. Relatively large concentrations of these three trace elements were attributed primarily to reservoir applications of copper sulfate to control algal blooms and vehicular traffic within the basins.

Sediment concentrations of arsenic, chromium, and nickel exceeded the consensus-based threshold effect concentration (TEC) for harmful effects on sediment-dwelling organisms in all samples from every reservoir. For copper, lead, and zinc, the results were more variable. In the case of copper, sediment concentrations frequently exceeded the probable effect concentration (PEC) for harmful effects on sediment-dwelling organisms in samples from the reservoirs that had been treated with copper sulfate. For lead, sediment concentrations frequently exceeded the TEC for several reservoirs and reflected the history of leaded gasoline use. Results for Crystal Lake indicated that, following the phase out of leaded gasoline, it will take at least several decades for lead in newly deposited reservoir bottom sediments to return to historical baseline concentrations. Sediment concentrations of zinc typically exceeded the TEC for several reservoirs and likely reflect inputs from vehicular tire wear. Cadmium concentrations in samples from all reservoirs typically were less than the TEC. Trace element concentrations in samples from a sediment core for Crystal Lake (long historical record) and Otis Creek Reservoir (relatively pristine basin) indicated that, for certain trace elements in certain areas, historical baseline concentrations may exceed the TECs prior to the effects of substantial nonagricultural human activity in the basin.

Overall, a comparison based on the percentage of samples that exceeded the TECs indicated that the sediment quality for Bronson City Lake, Crystal Lake, Gardner City Lake, and Lake Afton was most affected by nonagricultural human activity. The results indicated that the effects of nonagricultural human activity on sediment quality were relatively moderate for Mission Lake and relatively minimal for Centralia Lake, Otis Creek Reservoir, and Pony Creek Lake.

An analysis of sediment cores can provide information that may be used to partly reconstruct historical sediment-quality and water-quality records and to determine a present-day baseline with which to evaluate long-term changes in reservoir sediment and water quality that may be related to changes in human activity in the basin. Moreover, such information may be used to assist in the development, implementation, evaluation, and revision of total maximum daily loads for sediment and associated chemical constituents that contribute to the water-quality impairment of reservoirs.

REFERENCES CITED

American Society for Testing and Materials (2000). Standard Practice for High-Resolution Gamma-Ray Spectrometry of Water, *in* Annual Book of ASTM Standards, section 11, Water and Environmental Technology. ASTM, West Conshohocken, Pennsylvania, v. 11.02, D 3639–98a, pp 294–304.

Arbogast, B.F. (1996). Analytical Methods Manual for the Mineral Resource Surveys Program. U.S. Geological Survey Open-File Report 96–525.

Baudo, Renato, Giesy, J.P., and Muntau, Herbert, eds. (1990). Sediments—Chemistry and Toxicity of In-Place Pollutants. Lewis Publ., Ann Arbor, Michigan.

Briggs, P.H., and Meier, A.L. (1999). The Determination of Forty Two Elements in Geological Materials by Inductively Coupled Plasma-Mass Spectrometry. U.S. Geological Survey Open-File Report 99–166.

Callender, Edward, and Rice, K.C. (2000). “The Urban Environmental Gradient—Anthropogenic Influences on the Spatial and Temporal Distributions of Lead and Zinc in Sediments,” Environmental Science & Technology, 34(2), pp 232–238.

Callender, Edward, and Van Metre, P.C. (1997). “Reservoir Sediment Cores Show U.S. Lead Declines,” Environmental Science & Technology, 31(9), pp 424A–428A.

Charles, M.J., and Hites, R.A. (1987). “Sediments as Archives of Environmental Pollution Trends,” chap. 12, *in* Hites, R.A., and Eisenreich, S.J., eds., Sources and Fates of Aquatic Pollutants. American Chemical Society, Washington, D.C., Advances in Chemistry Series 216, pp 365–389.

Davies, B.E. (1990). Lead, chap. 9, *in* Alloway, B.J., ed., Heavy Metals in Soils. John Wiley & Sons, New York, pp 177–196.

Fishman, M.J., and Friedman, L.C., eds. (1989). Methods for Determination of Inorganic Substances in Water and Fluvial Sediments. U.S. Geological Survey Techniques of Water-Resources Investigations, book 5, chap. A1.

High Plains Regional Climate Center (2002). Historical Data Summaries: Information available on the Web, accessed August 21, 2002, at http://www.hprcc.unl.edu/

Juracek, K.E. (2004). Sedimentation and Occurrence and Trends of Selected Chemical Constituents in Bottom Sediment of 10 Small Reservoirs, Eastern Kansas. U.S. Geological Survey Scientific Investigations Report 2004-5228.

Kansas Applied Remote Sensing Program (1993). Kansas Land Cover Data Base, 1:100,000 scale. Lawrence, Kansas, Data Access and Support Center, available on CD.

MacDonald, D.D., Ingersoll, C.G., and Berger, T.A. (2000). "Development and Evaluation of Consensus-Based Sediment Quality Guidelines for Freshwater Ecosystems," Archives of Environmental Contamination and Toxicology, 39, pp 20-31.

Pais, Istvan, and Jones, J.B., Jr. (1997). The Handbook of Trace Elements. St. Lucie Press, Boca Raton, Florida.

U.S. Environmental Protection Agency (1991). Guidance of Water Quality-Based Decisions—the TMDL Process. Office of Water, Washington, D.C., Report EPA440/4–91–001.

U.S. Environmental Protection Agency (1997). The Incidence and Severity of Sediment Contamination in Surface Waters of the Unted States, Volume 1—National Sediment Quality Survey. Office of Science and Technology, Washington, D.C., Report EPA823-R-97-006.

U.S. Environmental Protection Agency (2000). National Air Pollutant Emission Trends, 1990–1998. Office of Air Quality, Research Triangle Park, North Carolina, Report EPA454/R–00–002.

Van Metre, P.C., and Callender, Edward (1996). "Identifying Water-Quality Trends in the Trinity River, Texas, USA, 1969–1992, Using Sediment Cores from Lake Livingston," Environmental Geology, 28(4), pp 190–200.

Van Metre, P.C., and Mahler, B.J. (2004). "Contaminant Trends in Reservoir Sediment Cores as Records of Influent Stream Quality," Environmental Science & Technology, 38(11), pp 2978–2986.

Zoumis, Theofanis, Schmidt, Astrid, Grigorova, Lidia, and Calmano, Wolfgang (2001). "Contaminants in Sediments— Remobilisation and Demobilisation," The Science of the Total Environment, 266(1-3), pp 195–202.