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Selenium in Reservoir Sediment from the Republican River Basin

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Reservoir sediment quality is an important environmental concern because sediment may act as both a sink and a source of water-quality constituents to the overlying water column and biota. Once in the food chain, sediment-derived constituents may pose an even greater concern due to bioaccumulation. An analysis of reservoir bottom sediment can provide historical information on sediment deposition as well as magnitudes and trends in constituents that may be related to changes in human activity in the basin. The assessment described in this fact sheet was initiated in 1997 by the U.S. Geological Survey (USGS), in cooperation with the Bureau of Reclamation (BOR), U.S. Department of the Interior, to determine if irrigation activities have affected selenium concentrations in reservoir sediment of the Republican River Basin of Colorado, Kansas, and Nebraska.

Background

In the Republican River Basin (fig. 1), selenium is an environmental concern due to the presence of seleniferous soils, outcrops of the Pierre Shale, and wide-spread irrigation. These factors may combine to produce high concentrations of selenium in surface water at some sites located immediately downstream from irrigation return flows. Public Law 99–294 (1986) requires BOR to investigate soil characteristics that may result in toxic or hazardous irrigation return flows (Bureau of Reclamation, 1997). Of interest to BOR is an assessment of the magnitude and extent of selenium concentrations within the basin and what effects, if any, Federally supported irrigation activities are having. Specific objectives of this assessment were to determine background selenium concentrations in reservoir sediment, changes in selenium concentrations with time, and the potential effects of irrigation on selenium concentrations.

Basin Description

The Republican River has a drainage area of about 24,900 square miles that includes parts of Colorado, Kansas, and Nebraska (fig. 1). The topographically diverse basin is underlain by sedimentary rock ranging in age from Cretaceous to late Quaternary. A major geologic unit in the basin is the Ogallala Formation (Pliocene age), which is underlain in part by the Pierre Shale. The Pierre Shale is known to contain selenium and is exposed in parts of the basin (Bureau of Reclamation, 1996) (fig. 1). Soils in the basin are productive and used mostly for growing winter wheat,

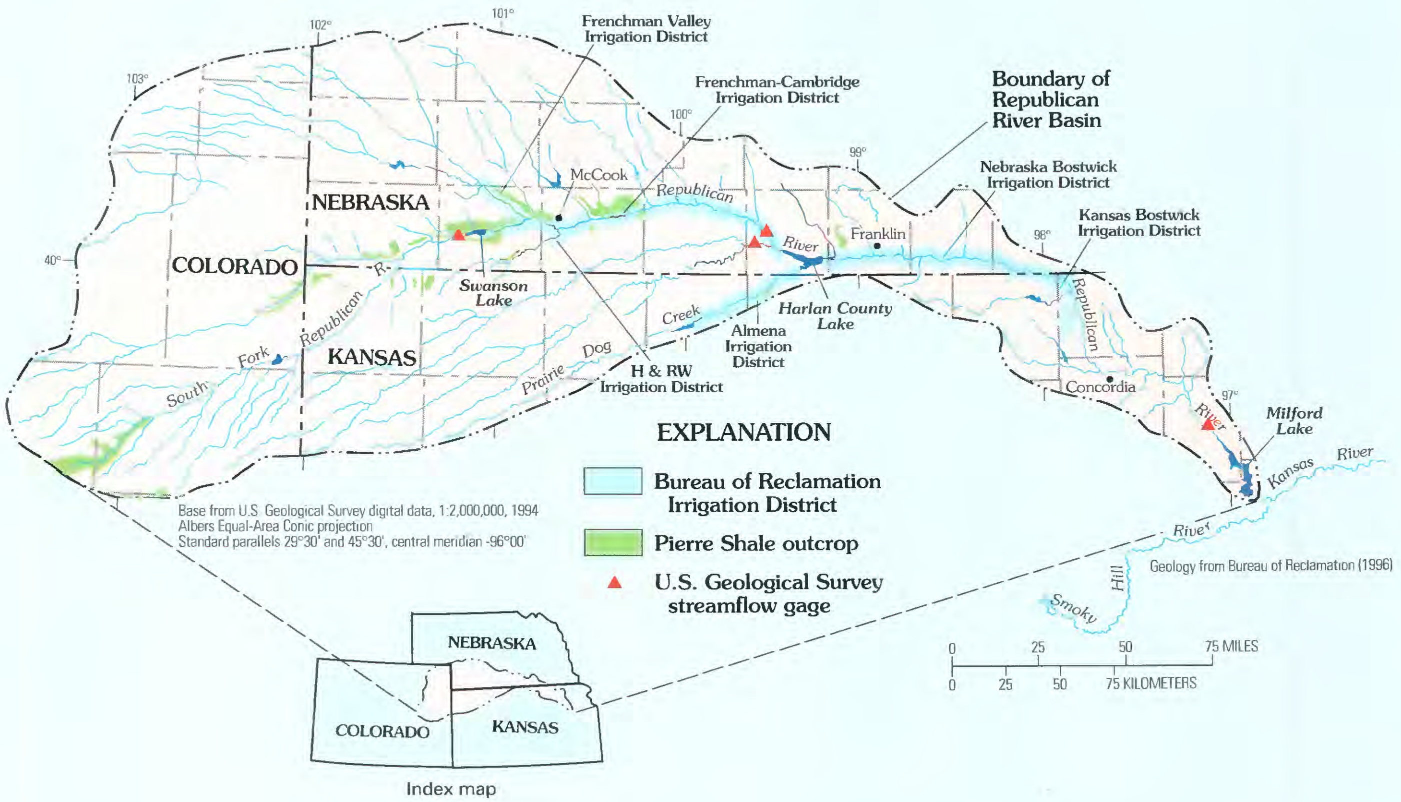

Figure 1. Location of reservoirs, Bureau of Reclamation irrigation districts, and Pierre Shale outcrops in the Republican River Basin.

grain sorghum, soybeans, corn, and sugar beets. More than 50 percent of the basin is cropland. The basin has variable climate with mean annual precipitation ranging from about 18 inches in the west to about 30 inches in the east (Bureau of Reclamation, 1996). Streamflow regimens of the Republican River and several of its tributaries have been altered by the construction of several reservoirs (fig. 1), as well as diversion dams and canals, many of which were built for the purpose of increasing irrigation within the basin.

Irrigation in the basin dates back to at least the 1850's. By the 1940's, prior to completion of BOR irrigation projects, an annual average of about 41,000 acres were irrigated in the basin, mostly using unregulated streamflow (U.S. Army Corps of Engineers, 1967). In 1996, approximately 1,900,000 (12 percent) of the 15,900,000 acres of farmland within the basin were irrigated. Of the total acres irrigated in 1996, about 137,000 acres (7 percent) received water from BOR irrigation projects (Bureau of Reclamation, 1997). Figure 2 shows the history of irrigation development in the basin from 1949 through 1992. In 1995, total diversions for irrigation in the basin were estimated to be about 2,335,000 acre-feet (Joan Kenny, U.S. Geological Survey, written commun., 1998). Of that total, about 255,000 acre-feet (11 percent) were used by the BOR's six irrigation districts (Judy Catt, Bureau of Reclamation, written commun., 1998) (fig. 1).

Selenium, a Naturally Occurring Trace Element

Selenium can be either beneficial or toxic to plants, animals, and humans depending on its concentration. Found throughout the environment, selenium is derived mainly from rock weathering. In the northern Great Plains, the parent material for selenium-rich soils is the Pierre Shale (Cretaceous age). Distribution processes for selenium include volcanic activity, combustion of fossil fuels, soil leaching, ground-water transport, metabolic uptake and release by plants and animals, sorption and desorption, chemical or bacterial reduction and oxidation, and mineral formation. In most oxygen-rich environments the dominant forms of selenium are selenite and selenate. Selenate is highly mobile, easily leached from soils, and readily taken up by plants. Although natural water tends to have low concentrations of selenium, relatively high concentrations can occur if the water is alkaline or if it leaches and drains seleniferous rocks and soils (McNeal and Balistrieri, 1989). Selenium concentrations equal to or greater than 4.0 mg/kg (milligrams per kilogram) in sediment are of concern for fish and wildlife because of food-chain bioaccumulation (Lemly and Smith, 1987).

Methods

The objectives of the assessment were accomplished by collecting and analyzing bottom sediment from three reservoirs in the Republican River Basin—Swanson Lake and Harlan County Lake in Nebraska and Milford Lake in Kansas (fig. 1). Swanson Lake, completed in 1953, was selected to define background sediment concentrations of selenium as well as trends in selenium concentrations immediately upstream from the Frenchman-Cambridge Irrigation District (fig. 1). Harlan County Lake, completed in 1952, was selected to define background sediment concentrations of selenium immediately upstream from the Nebraska and Kansas Bostwick Irrigation Districts (fig. 1), and trends in selenium concentrations at the midpoint of the BOR-irrigated reach of the Republican River Basin. In this assessment, background is defined as the sediment concentrations of selenium that are representative of conditions that predate the period of major irrigation development in the basin, which began in the mid-1960's (fig. 2). Milford Lake, completed in 1967, was selected to assess trends in selenium concentrations resulting from cumulative effects throughout the entire basin.

In May and June 1997, bottom-sediment cores were collected near the dam at two sites for each lake. The cores were collected near the dam because the sediment is least likely to be disturbed (for example, by biological activity, human activity, or wind-induced currents). Also, sediment near the dam will have the smaller grain sizes, which are most likely to contain selenium. The cores penetrated through the entire thickness of reservoir sediment and into the original land-surface (or channel-bed) material. At each site, four cores were collected using a gravity corer. Multiple cores were required to provide sufficient sediment material for laboratory analyses. Each core was divided into either 5 or 10 subsamples depending on the total sediment thickness.

For each site, separate cores were sampled and analyzed for selenium, sediment characteristics (that is, bulk density, percent moisture, and grain size), and age dating. The total recoverable analyses for selenium were performed at the BOR laboratory in Bismarck, North Dakota. The analyses of sediment characteristics were performed at the USGS laboratory in Lawrence, Kansas. To define

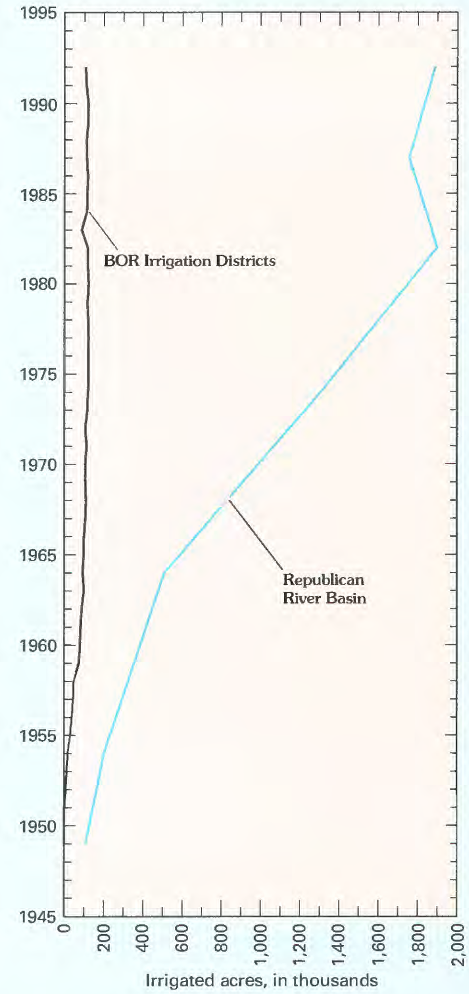

Figure 2. Irrigated acres in Republican River Basin and BOR irrigation districts, 1949–92 (data from Judy Catt, Bureau of Reclamation, written commun., 1998).

sampling variability, two sites were used at each reservoir (figs. 3–5). An assessment of analytical variability for selenium was attempted through analysis of duplicate samples at one site (fig. 5). Variability of the duplicate-analysis results was large, possibly due in part to the sampling technique used to obtain the duplicate samples.

Age dating of the bottom sediment was accomplished by determining the concentration of cesium-137 (^{137}Cs). ^{137}Cs is a radioactive isotope that is a by-product of nuclear weapons testing. Measureable concentrations of this isotope first appeared in the atmosphere in about 1952, peaked during 1963–64, and have since declined. ^{137}Cs is an effective marker for age dating of reservoir bottom sediment (Van Metre and others, 1997). It also can be used to demonstrate that the sediment is undisturbed if a relatively uniform decrease in ^{137}Cs concentrations follows the 1963–64 peak. The age-dating analyses were performed by Quanterra Laboratories, Denver, Colorado.

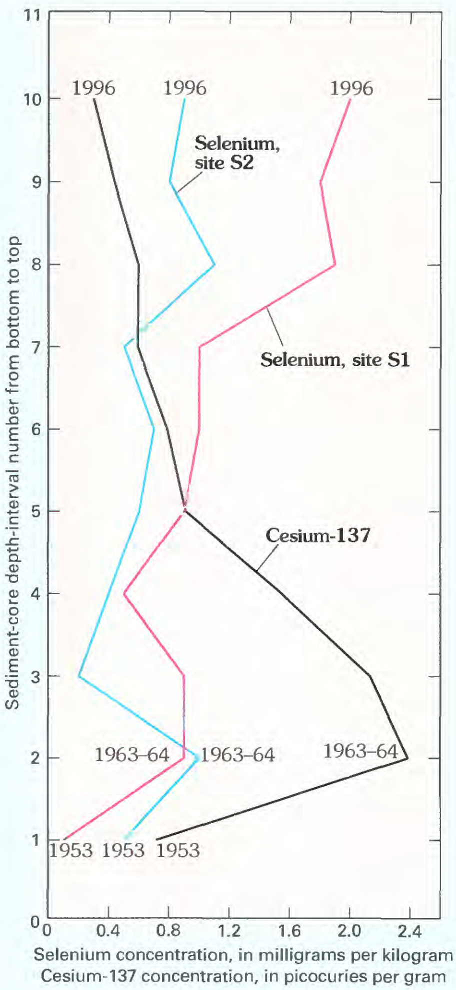

Figure 3. Selenium and cesium-137 profiles in sediment cores from Swanson Lake.

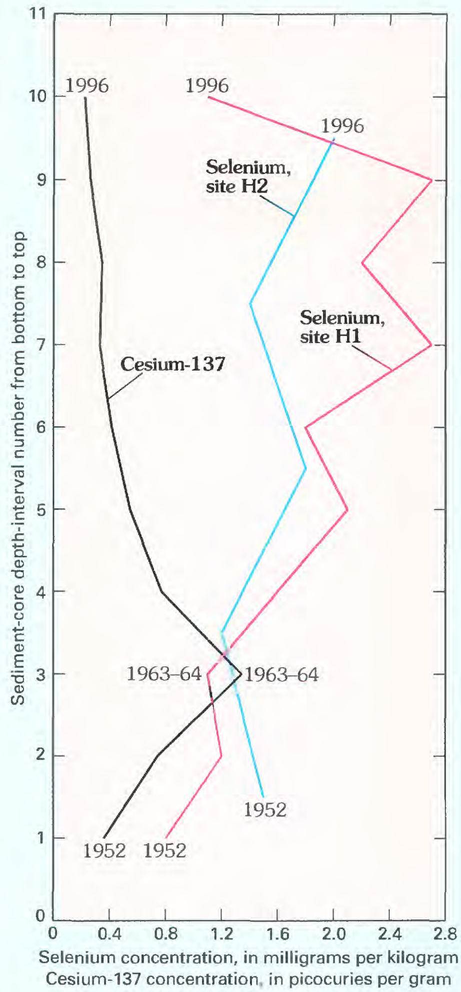

Figure 4. Selenium and cesium-137 profiles in sediment cores from Harlan County Lake.

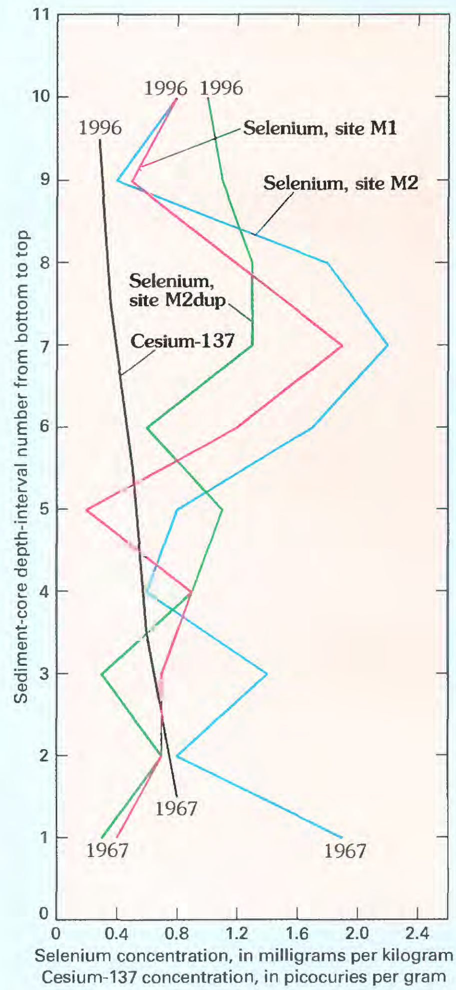

Figure 5. Selenium and cesium-137 profiles in sediment cores from Milford Lake.

Statistical analyses were performed to characterize the magnitudes of selenium concentrations in sediment cores from each lake and to test for trends. Trends in selenium concentration were examined by computing a Spearman's correlation coefficient and performing a t test (alpha = 0.05) for each sediment core from each lake. Also, a median test (alpha = 0.05) was performed to compare selenium concentrations among the reservoirs.

Selenium Concentrations and Relation to Irrigation

Background concentrations for selenium in reservoir bottom sediment were represented by sediment-core samples from Swanson and Harlan County Lakes, which were constructed prior to the major period of irrigation development in the Republican River Basin from the mid-1960's through the early 1980's (fig. 2). The ^{137}Cs results (figs. 3–5) indicated that the two deepest sample intervals from the Swanson and Harlan County Lake sediment cores were deposited prior to the mid-1960's and thus are representative of background conditions. In cores from Swanson Lake, background selenium concentrations (four samples) ranged from 0.1 to 1.0 mg/kg (milligram per kilogram) with a mean of 0.6 mg/kg. In cores from Harlan County Lake, background selenium concentrations (three samples) ranged from 0.8 to 1.5 mg/kg with a mean of 1.2 mg/kg. In comparison, post-background selenium concentrations in cores from Swanson Lake (16 samples) ranged from 0.2 to 2.0 mg/kg with a mean of 1.0 mg/kg. Post-background selenium concentrations in cores from Harlan County Lake (12 samples) ranged from 1.1 to 2.7 mg/kg with a mean of 1.8 mg/kg. In cores from Milford Lake, which represent post-background conditions, selenium concentrations (20 samples) ranged from 0.2 to 2.2 mg/kg with a mean of 1.0 mg/kg.

"Overall, the trend analyses indicate a general increase in selenium concentrations, through time, in sediment from all three reservoirs."

For Swanson Lake, both sediment cores indicated a trend of increasing selenium concentrations with decreasing depth (fig. 3). The respective Spearman's correlation coefficients for sites S1 and S2 were -0.92 and -0.47. The correlation for site S1 was statistically significant (two-sided p-value = 0.00014), whereas the correlation for site S2 was not (two-sided p-value = 0.17246). Likewise, for Harlan County Lake, both sediment cores indicated a trend of increasing selenium concentrations with decreasing depth (fig. 4). The respective Spearman's correlation coefficients for sites H1 and H2 were -0.56 and -0.50, neither of which was statistically significant (respective two-sided p-values were 0.09158 and 0.39100). However, if the most-recent (shallowest) depth interval is omitted from site H1, the resultant correlation is a statistically significant -0.94 (two-sided p-value = 0.00019). The most-recent depth interval may be anomalous as it presumably includes a large input of sediment resulting from the 1993 flood. Inspection of annual discharge data from USGS streamflow gages located immediately upstream from each reservoir (fig. 1) indicates that the 1993 flood was minor at Swanson Lake, pronounced at Harlan County Lake, and extreme at Milford Lake.

The initial results were mixed for Milford Lake (fig. 5). Sites M1 and M2 had respective

Spearman's correlation coefficients of -0.38 and 0.18, neither of which was statistically significant (respective two-sided p-values were 0.28141 and 0.62287). However, if the two most-recent depth intervals are omitted from sites M1 and M2, the respective Spearman's correlation coefficients (and associated significances) are -0.71 (two-sided p-value = 0.04807) and -0.30 (two-sided p-value = 0.47126). The two most-recent depth intervals may be anomalous as they presumably include a large input of sediment associated with extreme effects of the 1993 flood.

The possible effect of irrigation on selenium concentrations was assessed in two ways. First, background and post-background selenium concentrations were compared for sediment cores from Swanson and Harlan County Lakes. Although the small number of background sediment samples precluded a statistical analysis to determine significance, the post-background increases previously noted for both lakes indicate that irrigation within the basin may be having an effect on selenium concentrations.

Second, in an attempt to isolate the contributions of BOR irrigation projects, post-background selenium concentrations in sediment from Swanson Lake were compared to those from Harlan County and Milford Lakes using a median test. BOR irrigation projects are located in the river valleys upstream from both Harlan County and Milford Lakes. However, no BOR irrigation projects are located upstream from Swanson Lake (fig. 1). Post-background selenium concentrations in sediment from Swanson Lake (16 samples) were compared to those from Harlan County Lake (12 samples), and a significant difference was indicated (two-sided p-value = 0.00263). However, a comparison of post-background selenium concentrations in sediment from Swanson Lake with those from Milford Lake (20 samples) indicated no significant difference (two-sided p-value = 0.73732). Selenium concentrations in sediment from Harlan County Lake were also significantly different from selenium concentrations in sediment from Milford Lake (two-sided p-value = 0.03540). The respective median post-background selenium concentrations in sediment from Swanson, Harlan County, and Milford Lakes were 0.9, 1.8, and 0.8 mg/kg.

Because the distribution of BOR-irrigated acres between Swanson and Harlan County Lakes (51 percent) and between Harlan County and Milford Lakes (49 percent) is virtually equal, the observed difference in median post-background selenium concentrations in sediment from Harlan County Lake and Milford Lake does not appear to be explained by BOR irrigation. However, median post-background selenium concentrations in sediment from all three lakes do appear to be related to total irrigated acres (that is, BOR plus non-BOR irrigated lands). The distribution of total irrigated acres in the basin upstream from Swanson Lake (29 percent), between Swanson and Harlan County Lakes (54 percent), and between Harlan County and Milford Lakes (17 percent) parallels the median post-background selenium concentrations determined for sediment from the three lakes (table 1). Also, the primary increase in selenium concentrations (figs. 3–5) corresponds with the substantial increase in the number of irrigated acres in the basin (fig. 2). It is also noteworthy that most of the exposed Pierre Shale in the basin is located upstream from Harlan County Lake.

Table 1. Irrigated acres and median post-background selenium concentrations
[mg/kg, milligrams per kilogram]

Subbasin area	Percentage of total irrigated acres in basin	Percentage of Bureau of Reclamation irrigated acres in basin	Median post-background selenium concentration (mg/kg)
Upstream from Swanson Lake	29	0	0.9
Between Swanson and Harlan County Lakes	54	51	1.8
Between Harlan County and Milford Lakes	17	49	.8

Conclusions

As evidenced by a comparison of background and post-background selenium concentrations and the results of trend tests, irrigation appears to have increased selenium concentrations in reservoir sediment within the Republican River Basin. The changes in selenium concentrations attributable to BOR irrigation are likely commensurate with the percentage of total irrigated acres that receive water from BOR's six irrigation districts. Because most of the irrigated land and exposed Pierre Shale is located upstream from Harlan County Lake and median post-background selenium concentrations in sediment from Harlan County Lake are significantly larger than the median concentrations in sediment from Swanson and Milford Lakes, Harlan County Lake may be acting as a sink for selenium deposition within the basin.

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