Fluvial Sediment and Chemical Quality of Water in the Little Blue River Basin Nebraska and Kansas

GEOLOGICAL SURVEY WATER-SUPPLY PAPER 1819-H

Prepared as part of a program of the Department of the Interior for development of the Missouri River basin

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By JAMES C. MUNDORFF *and* KIDD M. WADDELL

CONTRIBUTIONS TO THE HYDROLOGY OF THE UNITED STATES

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GLOSSARY

Base flow (base runoff). Sustained or fair-weather runoff. In most streams, base flow is composed largely of ground-water effluent.

Equivalents per million. A unit for expressing the concentration of chemical constituents in terms of the interreacting values of the electrically charged particles, or ions, in solution.

Fluvial sediment. Material originating mostly from the disintegration of rocks and transported by, suspended in, or deposited from water; it includes the chemical and biochemical precipitates and the organic material, such as humus, which has reached such an advanced stage of disintegration and decomposition that the original structure and characteristics of the living organic unit are not recognizable.

Hardness. The water property attributable to the presence of alkaline earths, mainly calcium and magnesium.

Overland flow. The flow of rainwater or snowmelt over the land surface toward stream channels.

Particle-size classification. The classification recommended by the American Geophysical Union Subcommittee on sediment terminology (Lane and others, 1947, p. 937). According to this classification, clay-size particles have diameters between 0.0002 and 0.004 mm, silt-size particles have diameters between 0.004 and 0.062 mm, and sand-size particles have diameters between 0.062 and 2.0 mm.

Parts per million (ppm). A unit for expressing the concentration of dissolved chemical constituents by weight, usually as grams of constituents per million grams of solution.

Percent sodium. The ratio, expressed in percentage, of sodium to the sum of the positively charged ions (calcium, magnesium, sodium, and potassium)—all ions in equivalents per million.

Residual sodium carbonate (as defined by Eaton, 1950, p. 123–124). The amount of carbonate plus bicarbonate, expressed in equivalents per million, that would remain in solution if all the calcium and magnesium were precipitated as the carbonate.

Salinity. The dissolved mineral content or total concentration of solids in solution.

Suspended sediment. Sediment maintained in suspension by the upward components of turbulent currents or as a colloid.

Total sediment discharge. The weight of all the sediment passing a stream section in a unit time.

Water discharge. The rate of flow of a stream; includes dissolved solids and suspended sediment transported in the water.

Water type. The character of the water with respect to its dissolved mineral composition. It indicates the anion and cation present in the highest concentrations in equivalents per million.

FLUVIAL SEDIMENT AND CHEMICAL QUALITY OF WATER IN THE LITTLE BLUE RIVER BASIN, NEBRASKA AND KANSAS

By JAMES C. MUNDORFF and KIDD M. WADDELL

ABSTRACT

The Little Blue River drains about 3,350 square miles in south-central Nebraska and north-central Kansas. The uppermost bedrock in the basin is limestone and shale of Permian age and sandstone, shale, and limestone of Cretaceous age. Bedrock is exposed in many places in the lower one-third of the basin but elsewhere is buried beneath a thin to thick mantle of younger sediments, mostly of Quaternary age. These younger sediments are largely fluvial and eolian deposits but also include some glacial till. Consisting in large part of sand and gravel, the fluvial deposits are an important source of ground-water supplies throughout much of the upper two-thirds of the basin. Loess, an eolian deposit of clayey silt, is by far the most widespread surficial deposit.

The climate is continental. Temperatures ranging from —38° F to 118° F have been recorded in the basin. Average annual precipitation as low as 10.31 and as high as 49.32 inches has been recorded. During most years in the period 1956–62, when nearly all the water-quality data were obtained, annual precipitation and annual runoff were greater than normal. Flow-duration data indicate, however, that the flow distribution for the period was near normal.

The Little Blue River has the same suspended-sediment characteristics as nearly all unregulated streams in the Great Plains—a wide range in concentrations, low concentrations during low-flow periods, and high concentrations during almost all periods of significant overland runoff. The maximum instantaneous concentration normally occurs many hours before maximum water discharge during any given rise in stage; the maximum daily mean concentration during any given year normally occurs at a moderate stream stage, not during a major flood.

Suspended-sediment data for Little Blue River near Deweese, Nebr., which receives drainage from the upstream third of the basin, approximately, show that during the 1957–61 water years concentrations of 100 ppm (parts per million) or less prevailed about 42 percent of the time and concentrations of 1,000 ppm or less prevailed about 85 percent of the time. Observed concentrations ranged from 2 to 21,000 ppm; daily mean concentrations ranged from 2 to 13,800 ppm.

The discharge-weighted suspended-sediment concentration was computed as about 2,800 ppm at Little Blue River near Deweese, about 3,300 ppm near Fairbury (Endicott), and about 3,000 ppm at Waterville. These stations receive drainage from about one-third, two-thirds, and nearly all the basin, respectively. Water-utilization problems resulting from high concentrations are not significant in the basin; use of water from the Little Blue River is quantitatively negligible.

Concentrations and, consequently, discharges of sediment are greater at a given water discharge on a rising stage than at the same discharge on the falling stage of the same runoff event. Also, a wide range in sediment discharge occurs at similar water discharges during different runoff events. Daily sediment discharges at Little Blue River near Deweese ranged from about 1,400 to 16,000 tons at daily mean water discharges of about 500 cfs (cubic feet per second) and from about 7,500 to 28,000 tons at water discharges of about 1,000 cfs.

The estimated long-term sediment discharge at Little Blue River near Deweese is about 400,000 tons per year; near Fairbury, about 1,200,000 tons per year; and at Waterville, about 1,900,000 tons per year. The high sediment discharge from the downstream part of the basin is due to greater precipitation and runoff—not to higher concentrations of suspended sediment—in the downstream parts of the basin.

Nearly all the suspended sediment is silt and clay. The streambed material is mainly medium sand to gravel. The median particle size of bed material observed was about 0.73 mm near Deweese and about 0.77 mm near Fairbury.

A few computations of total sediment discharge of Little Blue River near Deweese indicate that suspended-sediment discharge is 95 percent or more of the total sediment discharge over a wide range of water discharge. Suspended silt and clay generally are 90 percent or more of the total sediment discharge.

The chemical quality of the water during base flow of the Little Blue River is determined mainly by ground-water effluent from the unconsolidated sediments that mantle the bedrock in the upper two-thirds of basin. Cretaceous rocks, which are exposed only in the lower one-third of the basin, have a significant effect upon the chemical quality in the lower basin.

Throughout the Little Blue River basin both the overland flow and the base flow are of the calcium bicarbonate type. The dissolved solids for flows representative of base flow near Deweese, near Endicott, and at Waterville were 273, 319, and 433 ppm, respectively, and for overland flow, 73, 84, and 101 ppm. Streamflow throughout the upper two-thirds of the basin is uniform in chemical composition. In the lower one-third of the basin the chemical composition of the streamflow varies with the proportions of base and overland flow below Endicott. Increased dissolved-solids content of the ground-water effluent downstream from Endicott between 1956 and 1960 caused the dissolved solids during low flows at Waterville to increase from 328 to 433 ppm.

A main-stem reservoir near Deweese could result in a dissolved-solids increase of about 90 ppm during low flow between Deweese and Endicott. The impounded water would be of lower dissolved-solids content, however, than the present low flow at Deweese. Sufficient releases of the more dilute water would improve the chemical quality during low flow in downstream reaches.

The chemical quality of both base flow and overland flow upstream from Endicott is suitable for irrigation.

Sewage effluents from Hebron and Fairbury could have an adverse effect on the chemical quality in the downstream reaches during periods of low flow. Increased urban or industrial growth could have a similar effect.

INTRODUCTION

The Little Blue River drains an area of about 2,475 square miles in south-central Nebraska and 875 square miles in north-central Kansas. Extending from Minden, Nebr., to Blue Rapids, Kans., the drainage basin is 137 miles long and has an average width of about 24 miles. (See fig. 1.) Data on the quantity and quality of fluvial sediment and on the chemical quality of streamflow have been collected by the U.S. Geological Survey at four main-stem sites in Nebraska, and by the U.S. Army Corps of Engineers and the State of Kansas at one site in Kansas. The location of the data-collection sites is shown in figure 1, and the types of data and periods of record for each site are shown in figure 2.

The purpose of this report is to describe and analyze the results of the site investigations and to evaluate present and potential problems related to the quality of water in the basin. The available data on water quality were not obtained as part of an integrated basin-wide investigation but were a response to an immediate need for information at a specific stream site. The data description and analysis in this report complements that necessary for utilization of the data in reservoir design and water project planning by other Federal agencies.

SETTLEMENT AND ECONOMY

The main settlement and the establishment of the present general pattern of human occupancy in the basin occurred between 1865 and 1880, although a few homesteads were established before 1865. During the past 80 years, there have been great changes in transportation, farming methods, sources and magnitude of income, average size of farms, amount of investment in equipment and land, and trade and marketing habits; nevertheless, the economy and culture have remained agrarian in outlook.

Hastings, Nebr., which had an estimated population of 23,219 in 1964, is partly within the basin. The only towns that are wholly within the basin and had populations exceeding 1,000 in 1960 are Fairbury, Nebr. (5,572), Minden, Nebr. (2,383), Hebron, Nebr. (1,920), and Washington, Kans. (1,506). Of the 50 towns and villages in the basin, all that have municipal water systems use ground water as a source of supply.

Industrial development is minor and is mainly concentrated in Hastings, where manufacture of agricultural equipment and processing of agricultural products are important to the local economy.

Livestock, wheat, corn, and grain sorghums are the major sources of agricultural income. During the past 20 years, agricultural production and the average size of farms have markedly increased while the labor required per unit of production has decreased.

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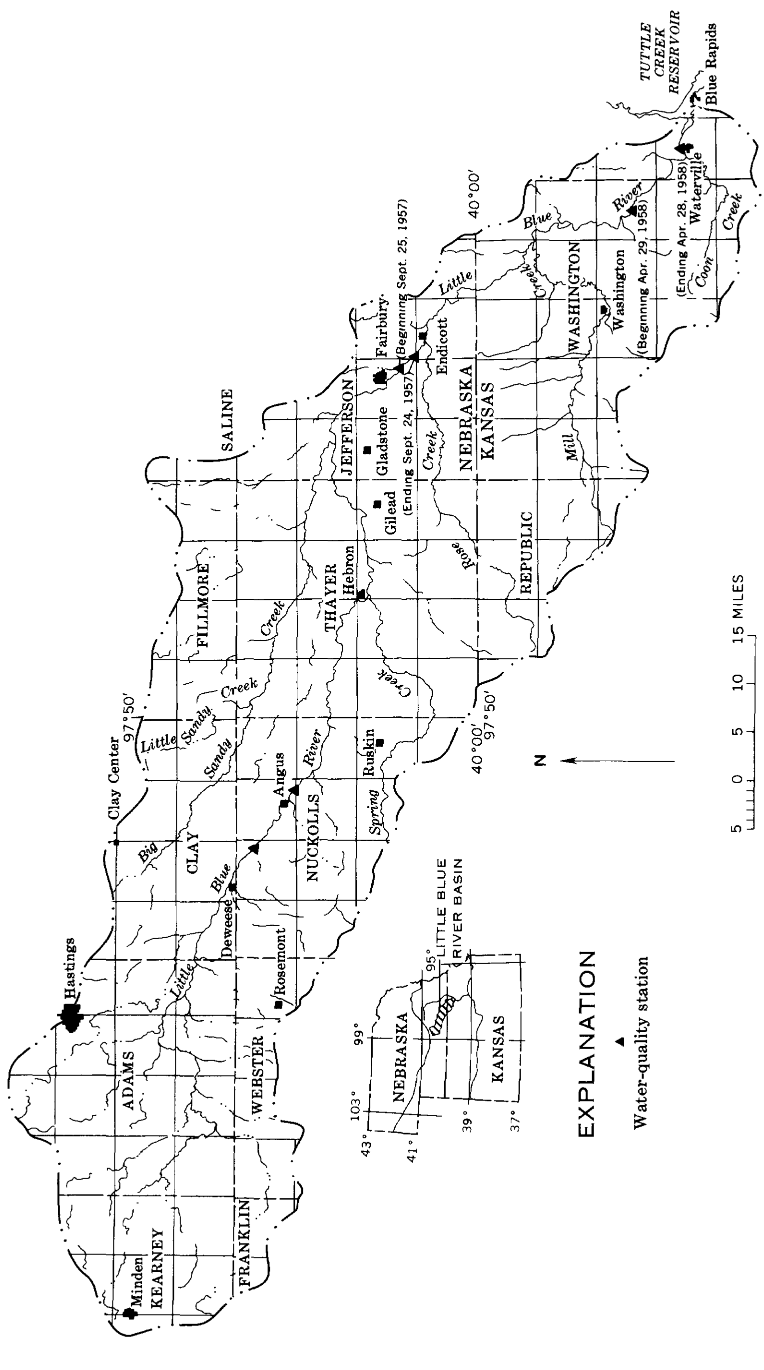

FIGURE 1.—Location of stations at which water-quality data were obtained.

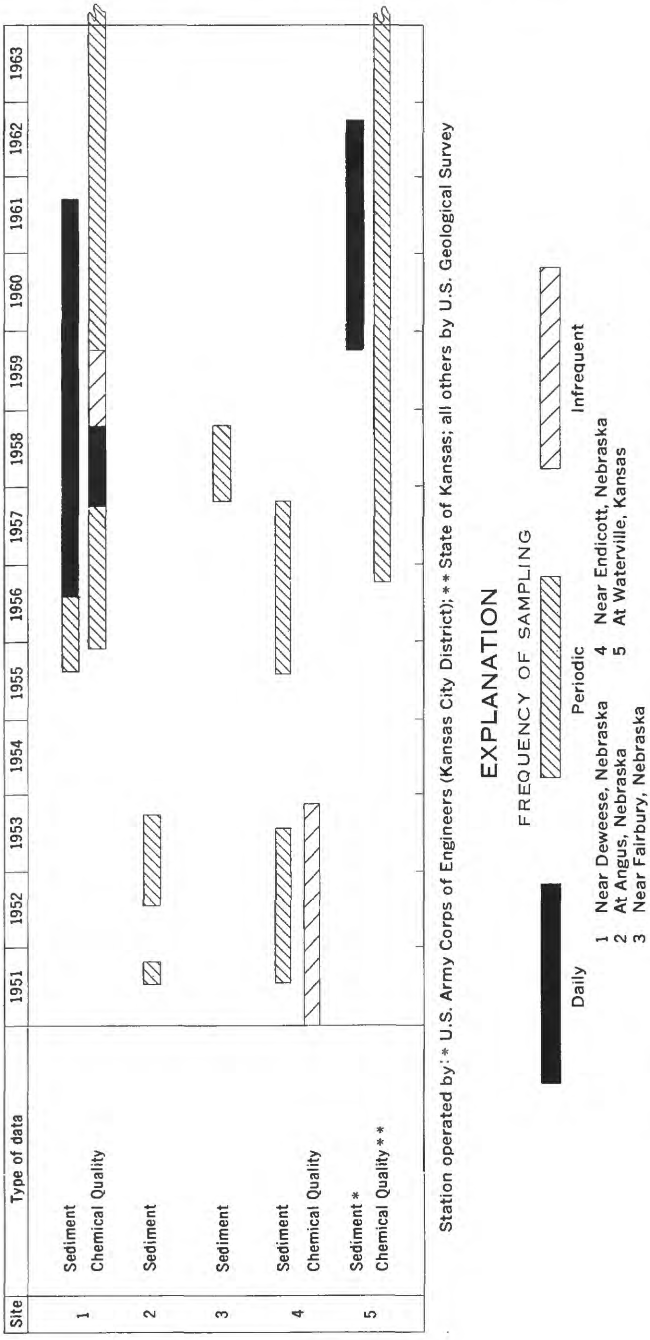

FIGURE 2.—Period of operation, type of data, and frequency of sampling at water-quality stations.

GEOLOGY AND TOPOGRAPHY

Throughout the upper and central parts of the Little Blue River basin, the uppermost bedrock is of Cretaceous age; in the lower part of the basin, it is partly of Cretaceous age and partly of Permian age. The Dakota Sandstone of Cretaceous age crops out in several places below Fairbury (fig. 3). Some beds in this formation are sufficiently permeable to transmit significant quantities of water, most of which is somewhat saline. In the upper part of the basin the

FIGURE 3.—Outcrop of Dakota Sandstone several hundred feet downstream from the water-quality station near Endicott, Nebr. Sandstone overlies weathered shale at this section. Small springs and seeps are common at the contact of the sandstone and shale.

bedrock is overlain in places by unconsolidated to poorly consolidated deposits of Tertiary age as much as 125 feet thick. Although the bedrock is exposed or is only thinly mantled by glacial or eolian deposits in much of the basin below Fairbury, elsewhere the bedrock and the Tertiary deposits as well are thinly to thickly mantled by a complex of glacial till and water- and wind-deposited sediments of Quaternary age.

The water-laid deposits of Quaternary age extend into the basin from the west. They consist in large part of fluvial sand and gravel but also include extensive deposits of silt and clay. The Quaternary deposits form an almost continuous sheet over a large part of the basin above Fairbury; they are thickest where they fill broad east-trending valleys that were eroded by streams in late Tertiary and early Pleistocene time, and thinnest on the divides between those valleys. Along a northwest-trending line through Fairbury, the fluvial deposits give way to glacial till, which extends into the basin from the northeast. The till was deposited during the Nebraskan and Kansan Glaciations of the Pleistocene, and the fluvial material was deposited during the same time and also during the Illinoian. Most of the fluvial deposits are both highly permeable and saturated and are therefore a major source of ground water for irrigation and municipal use.

A thin to thick mantle of loess, or wind-deposited clayey silt, overlies the fluvial deposits, and where these are absent, rests on the till or bedrock. Three different loess sheets—the Loveland (Illinoian), the Peorian (Wisconsin), and the Bignell (Wisconsin)—are recognized. The reddish tint of the Loveland and, where preserved, the fossil soils at the top of both the Loveland and the Peorian help to distinguish the loess sheets. According to Lugn (1935) the Loveland is as much as 80 feet thick and the Peorian as much as 100 feet. The Bignell is much thinner than either of the other two and less widespread.

The flood plains of the Little Blue River and its principal tributaries are underlain by alluvium of Recent age. The alluvium consists wholly of reworked Pleistocene sediments, and where it rests on Pleistocene sediments it cannot be distinguished from them. Only where alluvium rests directly on bedrock can its thickness be determined exactly.

An area of a few square miles in the upper part of the basin is underlain by wind-deposited sand.

Figure 4 shows the distribution of the surficial unconsolidated sediments and the areas where bedrock is exposed or only thinly mantled by unconsolidated sediments.

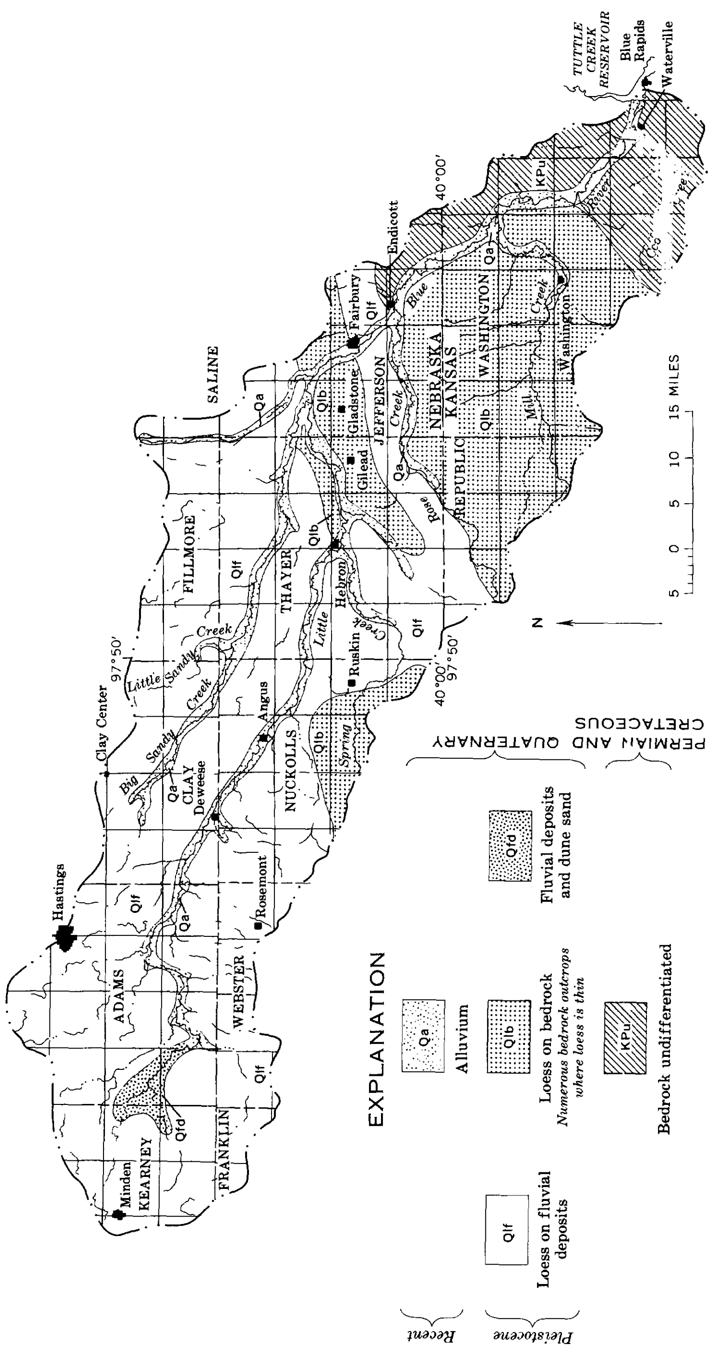

FIGURE 4.—Generalized surficial geology of the Little Blue River basin.

The topography of the basin ranges from nearly level loess plains having hundreds of small poorly drained depressions or "lagoons" (fig. 5) to severely eroded, dissected, steeply sloping areas of loess, sandstone, and shale. Except for narrow areas along the stream valleys, much of the area upstream from about Fairbury is level to gently rolling. Especially in southeastern Kearney County, central Adams and Clay Counties, and southwestern Fillmore County, level loessial uplands and wet depressions are common. In much of the downstream third of the basin, steep slopes and bedrock outcrops are common, the surface is rolling to intricately dissected, and an appreciable part of the land is in native vegetation.

The gradient of the Little Blue River averages about 5.2 feet per mile (fig. 6). Gradients for some principal tributaries range from an average of 6.0 feet per mile for Big Sandy and Rose Creeks to 11.2 feet per mile for Coon Creek.

FIGURE 5.—Poorly drained area in loess plains about 3 miles south of Clay Center, Nebr.

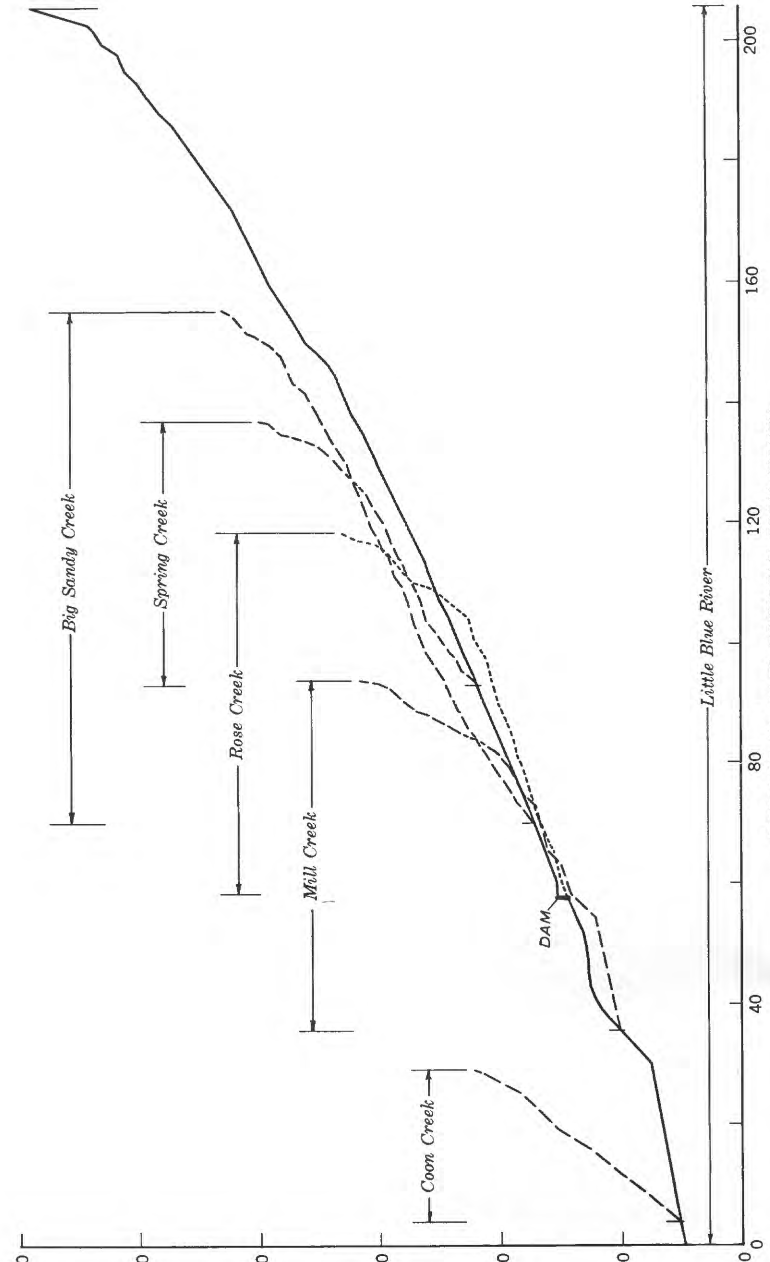

FIGURE 6.—Longitudinal profiles of the Little Blue River and selected tributaries.

The Little Blue River characteristically has a meandering channel (fig. 7) and unstable banks. A few field observations indicate that the migration of channel meanders is gradual during a wide range of stages from slightly more than base flow to bank-full stage. Major changes in the channel occur during the infrequent large floods, during which the banks are overtopped and new cutoff channels are sometimes established.

Valley length from the mouth to the headwaters of the Little Blue River is about 160 miles; channel length is about 205 miles. The ratio of channel length to valley length (1.28) suggests that meanders are common. Some reaches several miles long, however, have no well-developed meanders, whereas other reaches have numerous tight

FIGURE 7.—Meander in the Little Blue River near Endicott, Nebr. Former water-quality station is at bridge.

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meanders. For example, six different reaches having valley lengths ranging from about 1.5 to 7.5 miles have ratios of channel length to valley length ranging from 1.15 to 2.15. Tributary channels generally are more sinuous than the main stem. Reaches about 4 and 6 miles long on two randomly selected tributaries have ratios of channel length to valley length of 2.39 and 1.97.

SOILS

Soil characteristics reflect the geologic, topographic, climatic, and vegetation conditions under which the soils have developed during long periods of time. The basin is mainly within the zone of Chernozem soils, which are dark-colored soils developed in semiarid grasslands. Many different soil series, types, and phases have been mapped in the basin. No soil surveys have been published since 1927 for any counties in the basin, and only soil associations are shown in figure 8. A soil association is a group of defined and named soils associated in a characteristic geographic pattern; generally, only the two or three predominant soils within an association area are listed in the association name. Much of the land that is irrigated with ground water, and that may be irrigated with water from the planned Angus Reservoir on the Little Blue River, is of the Crete or Hastings soil series. These soils have been successfully irrigated for many years in central Nebraska, and under continuing intelligent agronomic and irrigation practices, they can continue to be irrigated successfully with either ground water from deposits of Pleistocene age or with surface water from the Little Blue River.

CLIMATE

The climate of the basin is continental; a wide annual range in temperature and precipitation, and great variability in weather from day to day and from year to year, are characteristic. Records of the U.S. Weather Bureau show that temperatures as low as −38°F and as high as 118°F have been recorded in the basin. Average annual precipitation has been as low as 10.31 inches at Clay Center and as high as 49.32 inches at Minden.

Precipitation decreases significantly between the mouth and the headwaters of the stream. At Blue Rapids, which is near the mouth of the Little Blue River, the average annual precipitation is about 28.8 inches. At Minden, which is at the headwaters about 130 miles northwest of the mouth, the average annual precipitation is about 22.2 inches.

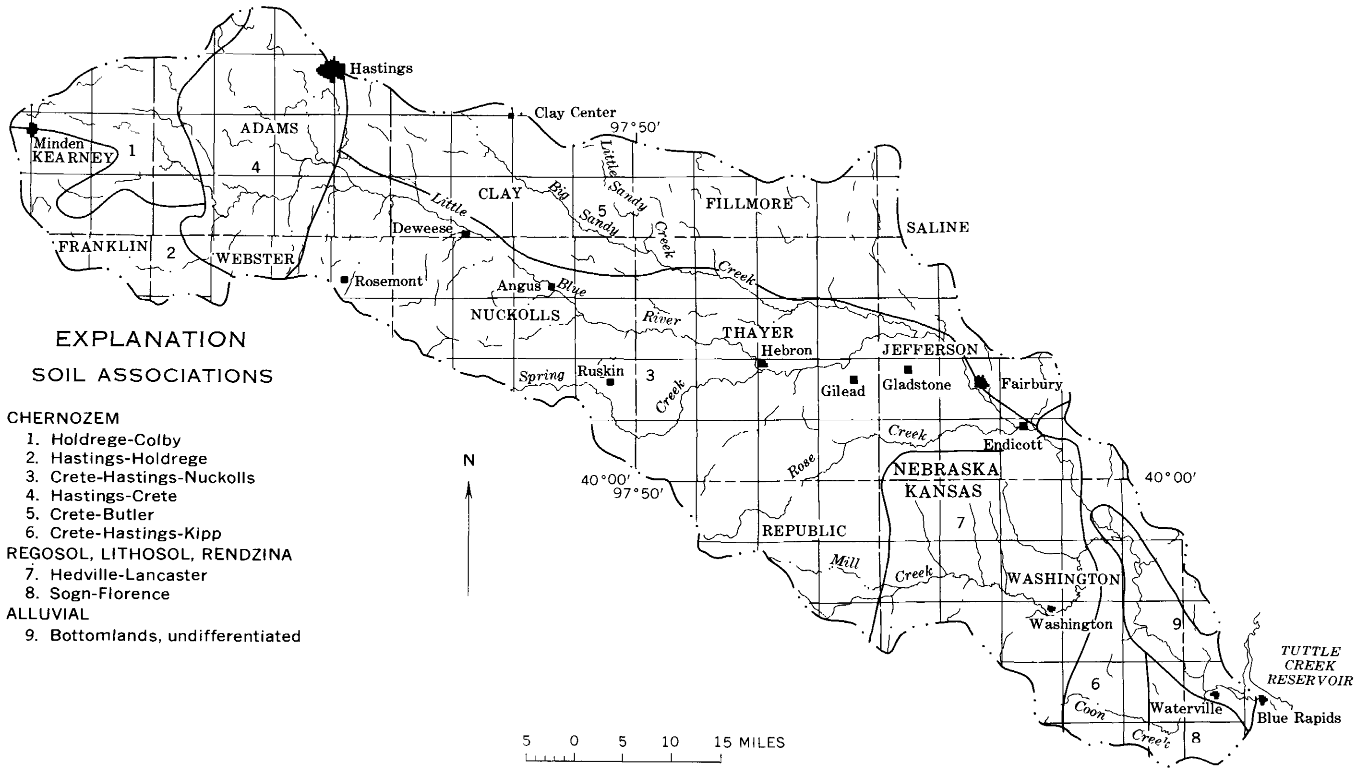

FIGURE 8.—Soil associations in the Little Blue River basin. **Adapted from U.S. Department of Agriculture (1957).**

RUNOFF AND EVAPORATION

The intensity of runoff is affected by the intensity and amount of precipitation and by the infiltration capacity of the soil. Information on maximum rate of runoff, in inches per hour, and on maximum volume of runoff, in inches of average depth over the watershed, is available for several small watersheds in the vicinity of Rosemont, Nebr. (U.S. Dept. Agriculture, 1958, 1963). The data are for 23 watersheds that range in size from about 3 to 3,490 acres, and for periods of record ranging from 13 to 20 years. Types and quality of vegetation varied from year to year in a single watershed and from watershed to watershed during a single year. Maximum rate of runoff was 7.67 inches per hour from a watershed of 3.8 acres. Maximum volume of runoff, in inches of average depth over the watershed, was 2.21, 3.49, and 3.62 for periods of 1, 12, and 24 hours from watersheds of 3 to 4.5 acres; maximum volume for an 8-day period was 4.99 inches from a watershed of 2,086 acres.

The maximum rate of runoff from watersheds of a few acres generally exceeds greatly the maximum rate from a basin of several hundred square miles of which the small watershed is a part. For example, the maximum rate of runoff during an 8-year period of record at Little Blue River near Deweese was 13,000 cfs (cubic feet per second), which is equivalent to a discharge rate of only about 0.012 inch per hour from the drainage area of 1,140 square miles; in contrast, the maximum rate of runoff was 7.67 inches per hour from a watershed of 3.8 acres. Further, runoff data from small adjacent watersheds and from different locations within a single small watershed indicate extreme variability of precipitation within short distances.

Erosion is probably as variable as runoff, and most of the sediment transported during a flood on such streams as the Little Blue River may be derived from a small percentage of the land surface of the basin. The intensity and amount of erosion are affected by the intensity of runoff and the erodibility of the soil. Greatest erosion does not necessarily occur as a result of the greatest rainfall intensity but rather as a result of high intensity of rainfall and runoff, high erodibility of the soil, and low infiltration capacity resulting either from natural soil characteristics or from antecedent moisture conditions.

Evaporation losses within the basin are fairly high. Average annual lake evaporation, computed from data obtained during 1946–55, ranges from about 48 inches in the east to 52 inches in the west; about 75 percent of this evaporation occurs during May to October (Kohler and others, 1959). Reliable data on evapotranspiration in the basin are not available. Only a small part of the precipitation recharges the ground-water reservoir. Keech and Dreeszen (1959) estimated that the average annual rate of recharge, in an area considered to be typical of the upland areas of the Little Blue River basin in Clay County, is about 1.6 inches. Average evapotranspiration is probably about half the average annual lake evaporation, measured in inches per year per unit area of free water surface. A very small part of the basin, however, is occupied by free water surface. Evaporation from free water surfaces is probably equal to evapotranspiration from less than 1 percent of the land surface of the basin.

During most years in the period 1956–62, when most of the water-quality data were obtained, precipitation and runoff were greater than normal (fig. 9). The exceptionally large amount of runoff from the basin in 1960 was due mainly to extremely high flows that resulted from rapid melting of a deep accumulation of snow. For example, nearly 30 percent of the discharge at Little Blue River near Fairbury for the 1960 water year occurred during March 26–31.

Streamflow records have been obtained at Little Blue River near Deweese only since the 1954 water year. For the 8-year period 1954–61, mean discharge near Deweese was 146 cfs; near Fairbury, 367 cfs; and at Waterville, 585 cfs. The drainage area upstream from Deweese is 49 percent of the drainage area upstream from Fairbury and 34 percent of the drainage area upstream from Waterville. However, the mean discharge near Deweese was only 40 percent of that near Fairbury and 25 percent of that at Waterville. During 1954–61, the annual mean discharge near Deweese ranged from 18 percent (1958) to 35 percent (1956) of that at Waterville.

Although the mean discharge near Deweese is disproportionately low relative to the percentage of the Little Blue River basin drainage area upstream from Deweese, the low flow (excluding post-flood bank storage and delayed overland flow) is disproportionately high. During extended periods of no overland flow from storms, the water discharge near Deweese commonly is 35 to 45 percent of the discharge at Waterville. The flow is then maintained principally by ground water from the thick deposits of sand and gravel of Pleistocene age in central Nebraska. These deposits become thinner downstream from the station near Deweese and are much thinner and discontinuous downstream from Fairbury. Therefore, the ground-water contribution to the Little Blue River from sand and gravel of Pleistocene age apparently decreases in the downstream third of the basin.

Flow-duration data presented by Furness (1959) suggest that channel losses through evaporation and seepage may be significant during prolonged low-flow periods in the reach between Endicott and Waterville (fig. 10). At Little Blue River near Fairbury (Endicott),

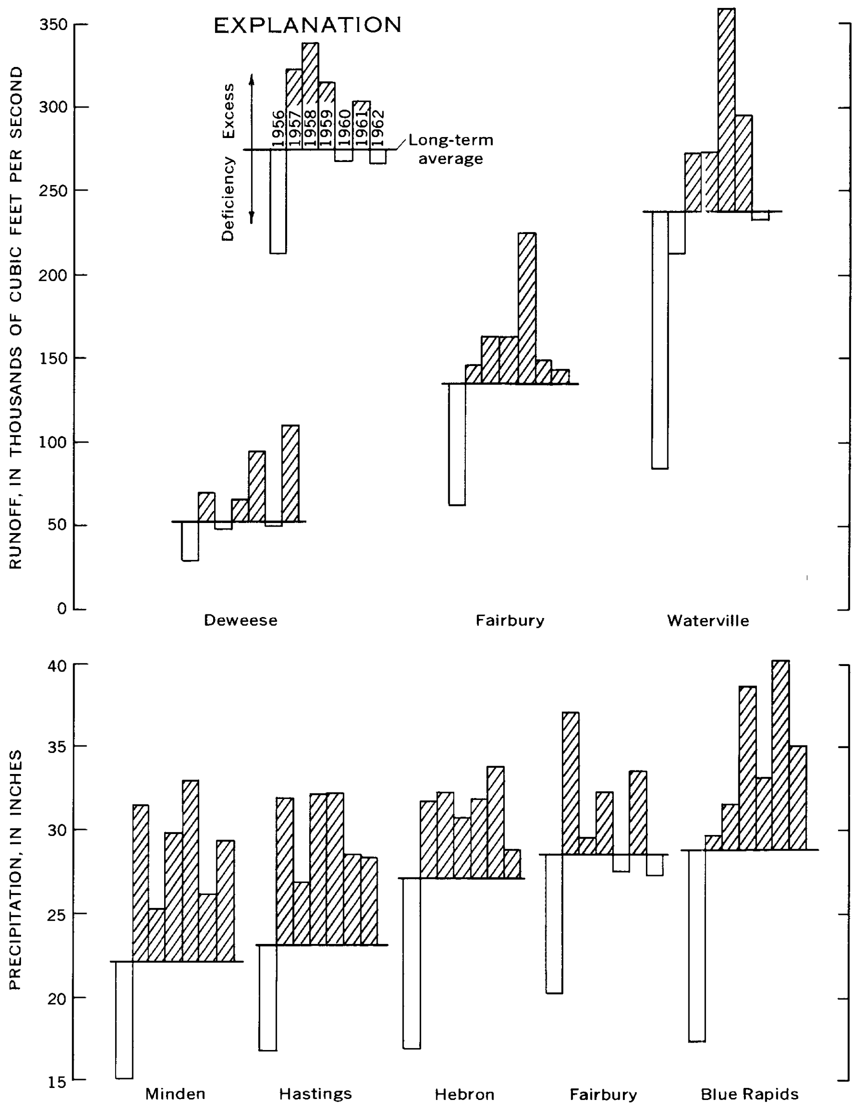

FIGURE 9.—Annual precipitation, annual runoff, and departures from normals at selected sites.

drainage area 2,320 square miles, discharges of about 115, 98, 85, and 61 cfs are equaled or exceeded 80, 90, 95, and 99 percent of the time, respectively. At Waterville, drainage area 3,330 square miles, discharges of 130, 105, 83, and 52 cfs are exceeded 80, 90, 95, and 99 percent of the time. Although 61 cfs is equaled or exceeded 99 percent of the time near Fairbury (Endicott), only about 52 cfs is equaled or exceeded 99 percent of the time at Waterville.

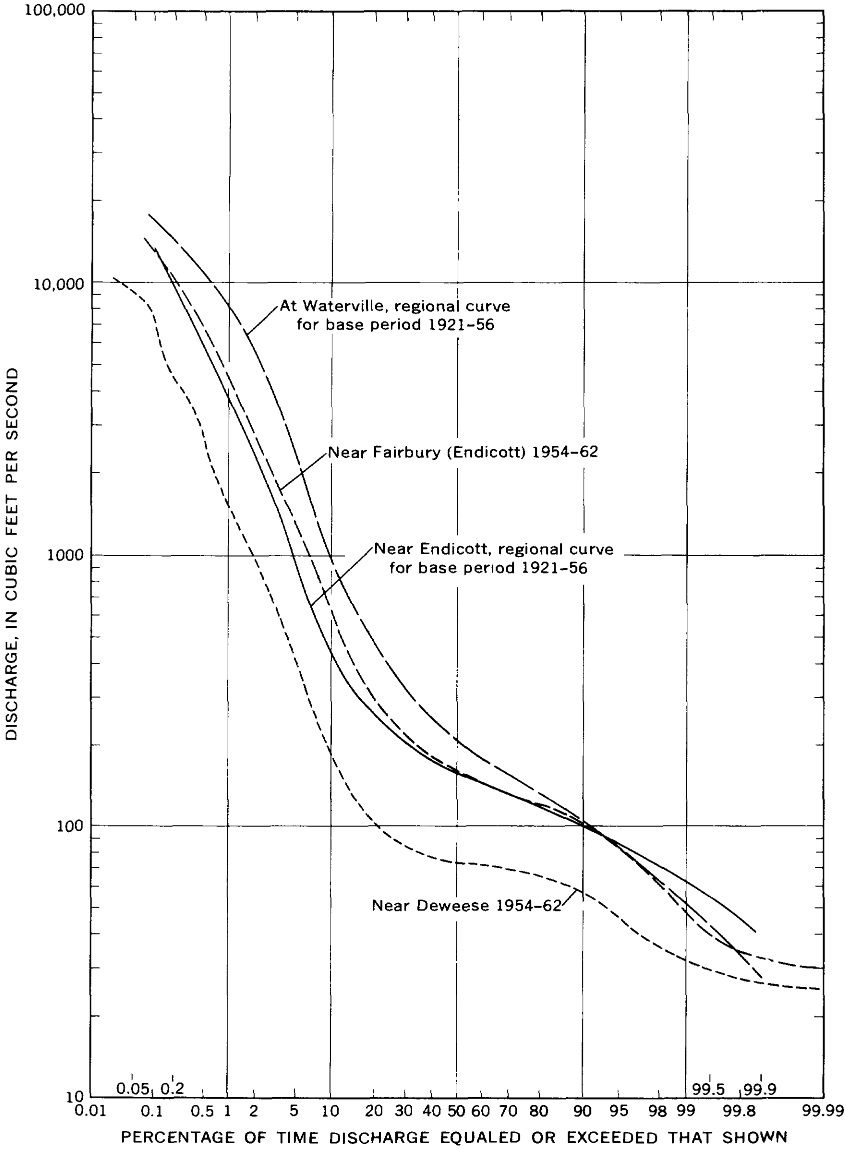

FIGURE 10.—**Flow-duration curves for Little Blue River near Deweese, near Fairbury (Endicott), and at Waterville.**

Comparison of the flow-duration curve for near Fairbury (Endicott) for the base period 1921–56 with the curve prepared from streamflow data for 1954–62 (fig. 10) indicates that flow distribution at that station was near normal for the main period of water-quality investigations. Further, the 1954–62 flow-duration curves for near Fairbury (Endicott) and near Deweese suggest that flow distribution at

Deweese was near normal for the period, although the total water discharge for any specific year may have been appreciably greater than or less than the long-term mean.

FLUVIAL SEDIMENT

Investigations of fluvial sediment in the Little Blue River basin were restricted to collection of routine data on suspended-sediment concentrations and discharges and on particle-size distribution of bed material. Fluvial-sediment data are not available for any tributaries of the Little Blue River. Data obtained by the Geological Survey at Little Blue River near Deweese and near Fairbury (Endicott) have been published in the annual series of water-supply papers entitled "Quality of Surface Waters of the United States." Daily suspended-sediment discharge data obtained by the Corps of Engineers (Kansas City District) for Little Blue River at Waterville during 1960–62 were used in preparing this report and are the only daily data available for the downstream two-thirds of the basin.

Both the Geological Survey and the Corps of Engineers used standard equipment and similar methods for collecting and analyzing the sediment samples. They also used similar methods to prepare the sediment-discharge records.

SUSPENDED-SEDIMENT CONCENTRATIONS

The Little Blue River has the suspended-sediment characteristics of nearly all unregulated streams in the Great Plains—a wide range in concentrations, low concentrations during low-flow periods, and high concentrations during almost all periods of significant overland runoff, regardless of the total amount of the runoff. Precipitation intensity, antecedent moisture conditions, and physical characteristics of the area of runoff mainly control the magnitude of suspended-sediment concentrations. During the period of observation, the maximum concentration during any rise in stream stage commonly occurred many hours before the maximum water discharge, not during the maximum water discharge or highest stage of the rise. For example, the annual maximum observed concentrations near Deweese ranged from 9,670 to 21,000 ppm (parts per million) during the period 1957–61, and each annual maximum occurred during the early part of a moderate rise in stage. During the same period the annual maximum daily mean concentration ranged from 5,740 ppm in 1957 to 13,800 ppm in 1960 at daily mean water discharges of 625 and 1,580 cfs, respectively. Thus, the annual maximum daily mean concentration is normally reached at a moderate stream stage, not during a major flood.

Daily mean concentrations as low as 2 ppm have been determined for Little Blue River near Deweese. Data for the 1957–61 water years show concentrations of 100 ppm or less about 42 percent of the time and concentrations of 1,000 ppm or less about 85 percent of the time (fig. 11). The concentration-duration curve for Deweese in figure 11 was prepared from data on daily mean concentrations and gives no indication of the frequency of hourly concentrations greater

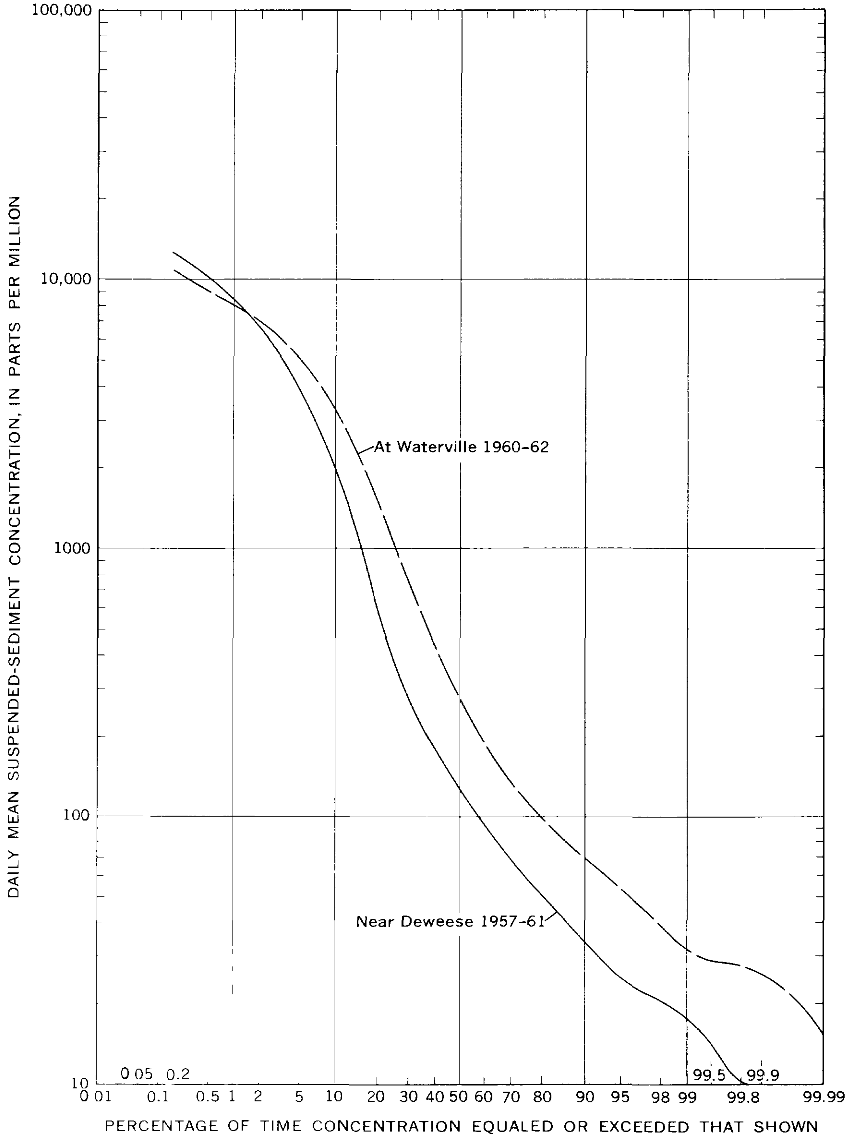

FIGURE 11.—Daily suspended-sediment-concentration–duration curves for Little Blue River near Deweese (1957–61) and at Waterville (1960–62).

than or less than daily means. For example, on June 28, 1959, the daily mean concentration was 9,890 ppm, although concentrations as high as 21,000 ppm were observed during part of the day. To determine the magnitude of the difference between a part of a concentration-duration curve based on daily mean concentrations and a curve based on hourly data, such a curve was constructed for seven periods that ranged in length from 11 to 30 days. During these periods daily mean concentrations were rarely less than 500 ppm. Comparison of the daily and hourly curves (fig. 12) shows that the significant difference between the curves is in their upper parts; for example, a daily mean concentration of 12,000 ppm was equaled or exceeded only 0.8 percent of the time, whereas a concentration of 12,000 ppm was exceeded 2 percent of the time according to the hourly curve. Concentration-duration curves prepared from data on daily mean con-

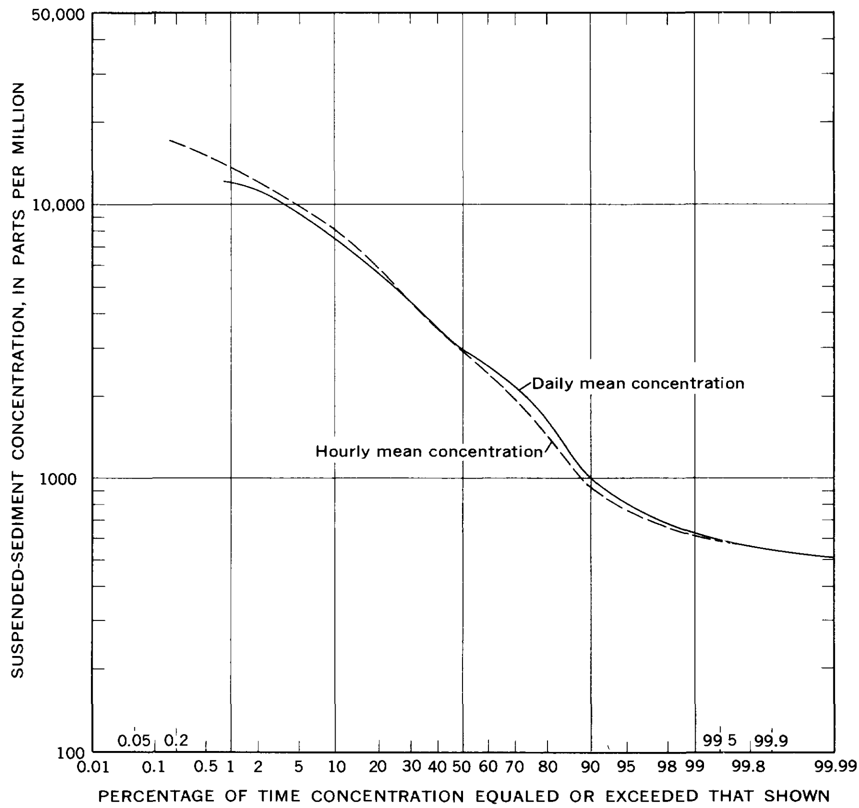

FIGURE 12.—Concentration-duration curves based on daily mean concentrations and hourly mean concentrations for 120 days of high concentration at Little Blue River near Deweese.

centrations do not indicate short-term recurrence intervals, seasonal or long-term trends in concentration, or frequency or magnitude of high concentrations that exceed the mean concentration for a given day.

Records obtained concurrently near Deweese and at Waterville during 1960–61 show that in 1960 water discharge was much above normal at both sites; in 1961 it was near normal near Deweese and slightly greater than normal at Waterville. Concentration-duration curves for the two sites for 1960–61 (fig. 13) show significant differences, however. A concentration of 200 ppm, for example, was equaled or exceeded at Waterville about 55 percent of the time but near Deweese only about 30 percent of the time. Discharge-weighted concentrations during 1960–61 were 3,100 ppm near Deweese and 3,580 ppm at Waterville; if the 10-day period March 27–April 5, 1960, is excluded from the record, the weighted concentrations are 3,170 ppm near Deweese and 3,250 ppm at Waterville. Thus, although the concentration-duration curves are significantly different, the discharge-weighted concentrations, which can be affected markedly by a few days of very high sediment discharge, are similar for the two sites.

Concentration curves shown in figure 11 for the complete period of daily record near Deweese (1957–61) and at Waterville (1960–62) are similar to those shown in figure 13 for the period of concurrent records (1960–61). The intersection of curves in each figure is at about the same point, and the curves are similar except for the distribution of concentrations below about 30 ppm.

Curves showing the average relation of suspended-sediment concentrations to water discharges that are equaled or exceeded for different percentages of time (fig. 14) indicate that the highest concentrations do not occur during the greatest water discharges. Near Deweese, near Fairbury (Endicott), and at Waterville, the concentrations tend to increase during increases in water discharge up to those discharges equaled or exceeded about 98–99 percent of the time. Average concentrations decrease sharply at the extremely high discharges that are equaled or exceeded 1–2 percent of the time.

Seasonal trends in concentrations and in water discharges at Little Blue River near Deweese are apparent in figure 15. Low concentrations and low water discharges prevail during October to March; high concentrations and water discharges usually occur during April to September. The seasonal trend shown for the station near Deweese prevails throughout the basin for streams that have perennial flow.

Water utilization problems resulting from high suspended-sediment concentrations during some periods are not significant in the basin. Use of water from the Little Blue River is almost negligible. Small

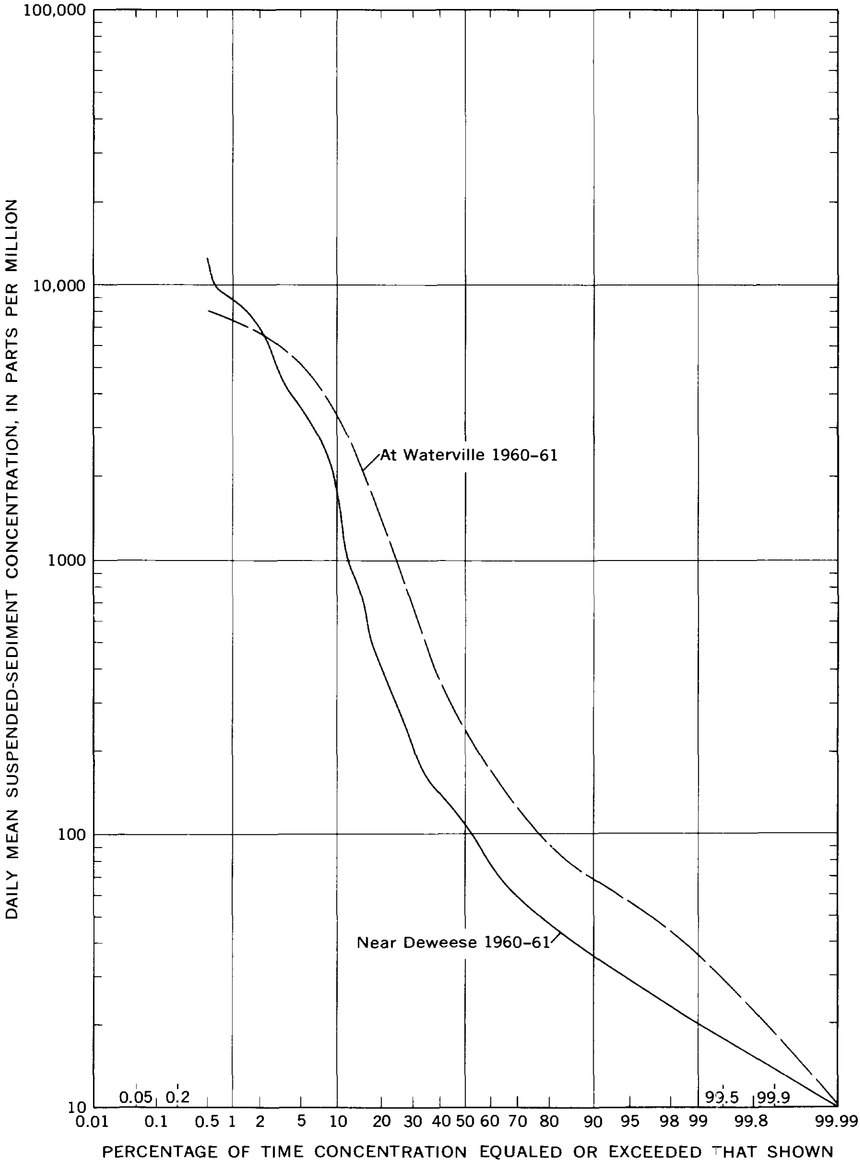

FIGURE 13.—Concentration-duration curves for Little Blue River near Deweese and at Waterville, 1960–61.

quantities of water are pumped from the stream for irrigation of valley land, and there is one small on-channel powerplant at Fairbury. Thus, suspended-sediment concentration problems associated with water treatment for municipal, industrial, and domestic uses obviously do not exist in the basin. If the water in the Little Blue River eventually

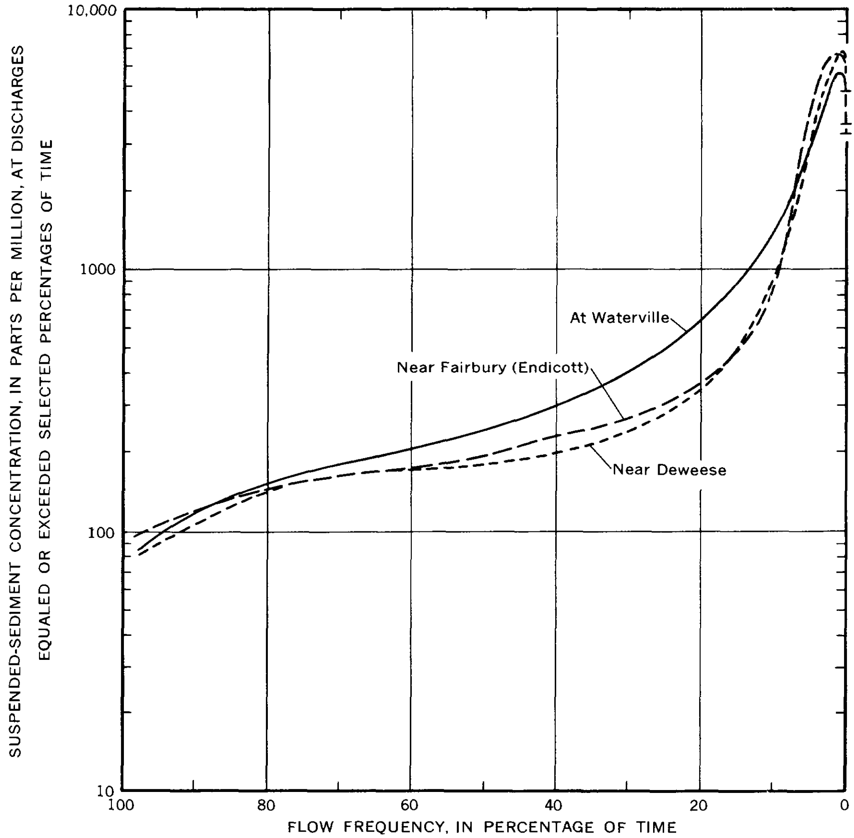

FIGURE 14.—Relation of average suspended-sediment concentrations to flow frequency in percentage of time.

is used by industries and municipalities, removal of sediment may be required during the 10–25 percent of the time when concentrations may range from 1,000 ppm for periods of several days to 20,000 ppm or more for periods of a few hours. Off-channel desilting basins and storage of sufficient water to satisfy needs during periods of high suspended-sediment concentration would probably be preferable to direct treatment for removal of large amounts of sediment.

The effect of major reservoirs, such as the proposed Angus Reservoir (total initial capacity—440,000 acre-ft), on the concentration of suspended sediment in the Little Blue River is not known. Similar reservoirs in the Great Plains have trap efficiencies of about 95 percent. Therefore, nearly all the sediment from the upstream third of the basin would be deposited in the reservoir, and concentrations in downstream reaches would be reduced markedly during periods when storm

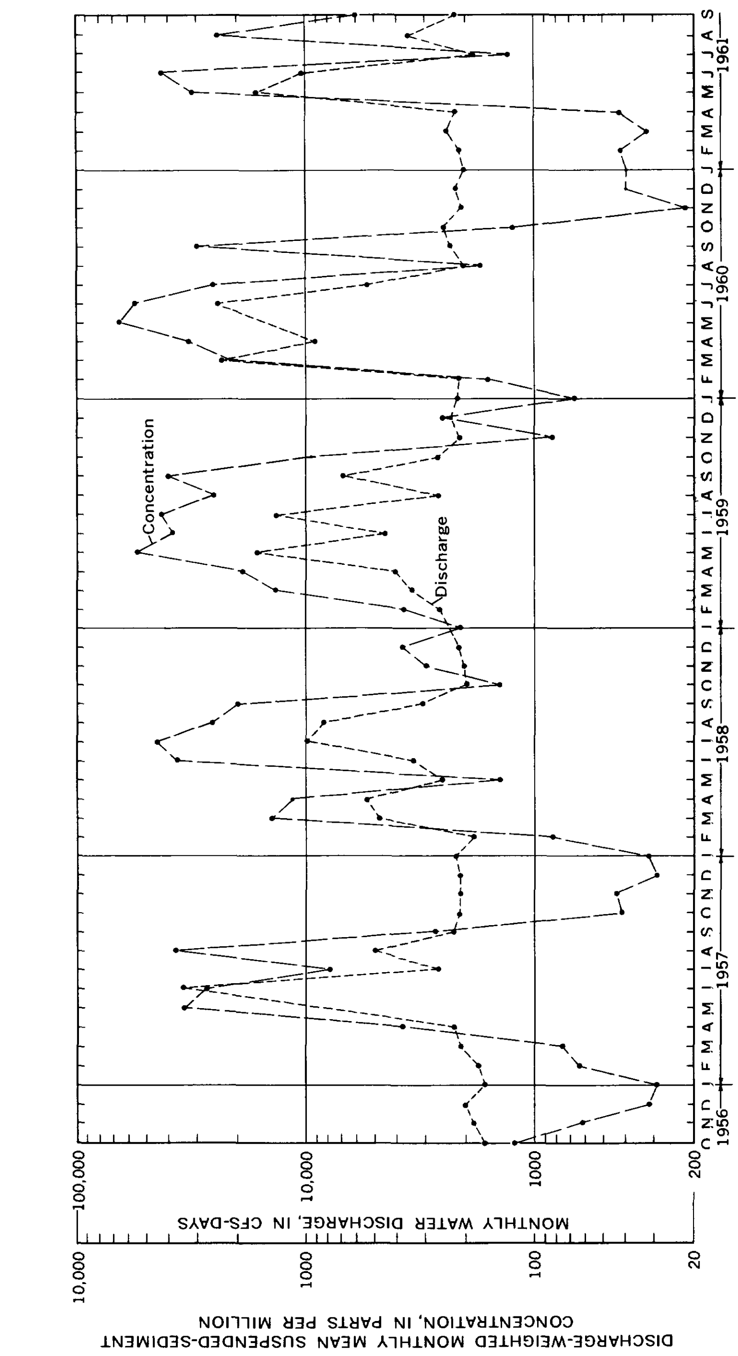

FIGURE 15.—Monthly water discharges and discharge-weighted monthly mean suspended-sediment concentrations at Little Blue River near Deweese, 1957–61.

runoff was restricted to the upstream third of the basin. During some periods, however, concentrations could be higher than they would have been under natural, unregulated conditions. For example, during periods of significant release of flood storage from such a reservoir, streamflow several times greater than natural base flow might be maintained for several days or weeks after a major flood; during such periods, concentrations might be expected to remain several times greater than they would have been during unregulated base flow. Thus, the general effects of regulation by such a reservoir would be to reduce sharply the annual discharge-weighted concentration and narrow sharply the concentration range for some distance downstream from the reservoir; to reduce the duration of high concentrations in downstream reaches; and, because of the effects of reservoir releases, possibly to increase the duration of moderate concentrations in downstream reaches. The effect of regulation by a major reservoir may be to improve markedly the quality of water, as to sediment content, during periods when floods would have occurred in the absence of regulation; conversely, regulation may result in poorer quality of water, as to sediment content, during periods when natural base flow is augmented by release of flood storage from a reservoir.

SUSPENDED-SEDIMENT DISCHARGE

Suspended-sediment discharge characteristics of a stream as a whole and at a particular section are affected by many conditions—the geology and soils of the drainage area, amount and distribution of precipitation, land use, land slopes, erodibility of bank and bed material of the channels, stream slope, and main-stem and tributary dams Suspended-sediment data were obtained in the Little Blue River basin to provide information for reservoir design purposes, not to evaluate the effects of conservation programs or to determine the sources of sediment and the predominant erosional process.

Suspended-sediment discharge of the Little Blue River varies with time and shows a general tendency to increase with water discharge. Furthermore, sediment concentration and discharge vary widely at any given water discharge. Sediment concentration and, consequently, sediment discharge are greater at a given water discharge during a rising stage than they are at the same discharge during the falling stage of the same runoff event. Also, sediment discharge at a given water discharge during one rising stage may differ greatly from that at the same water discharge during another rising stage. The curve in figure 16 shows the relation of sediment discharge to water discharge near Deweese. It represents only average conditions and does not indicate the wide range of values observed. For example,

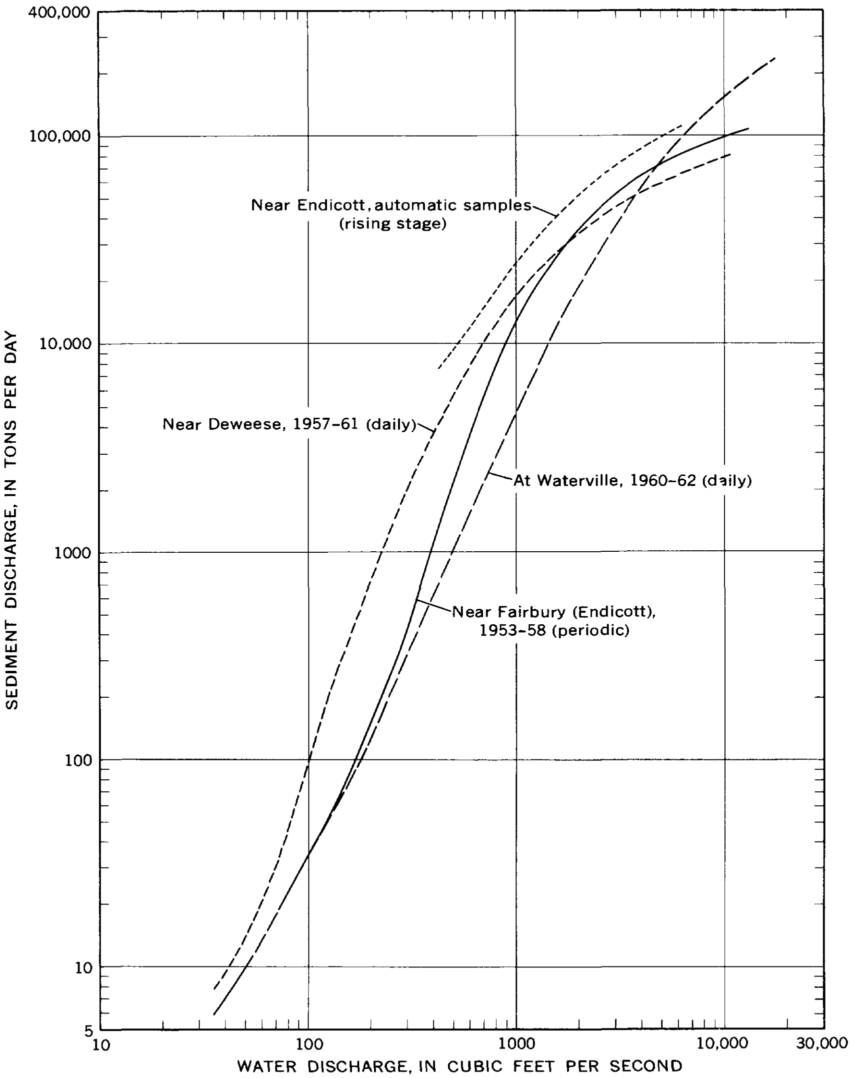

FIGURE 16.—Relation of sediment discharge to water discharge at Little Blue River near Deweese, near Fairbury (Endicott), and at Waterville.

daily sediment discharges ranged from about 2 to 300 tons at daily mean water discharges of about 70 cfs, from about 1,400 to 16,000 tons at daily mean water discharges of about 500 cfs, and from about 7,500 to 28,000 tons at daily mean water discharges of about 1,000 cfs.

The solution of reservoir design problems does not require detailed analysis of short-term variations in sediment load. Data obtained over a period of time sufficient to be representative of a wide range of climatic and runoff conditions allow for reliable predictions of the quantity of sediment that will be deposited in a reservoir. Computations are based on flow-duration data, on the relation of daily mean and instantaneous sediment discharges to daily mean and instantaneous water discharges, and on an evaluation of the representativeness of the short periods of streamflow and sediment investigations. Such computations indicate that the probable long-term average suspended-sediment discharge at Little Blue River near Deweese (drainage area 1,140 sq mi) is about 400,000 tons per year. The probable volume occupied by the sediment deposited in a main-stem reservoir near Deweese is between 250 and 275 acre-feet per year, depending on methods of reservoir operation and on probable trap efficiency of the reservoir. Trap efficiency of such a main-stem reservoir probably would be at least 93 percent and could be as high as 98 percent.

In most of the drainage area upstream from Deweese, precipitation was above normal during each year of sediment investigations (1957–61). Mean water discharge for 1960 was much greater than the mean for 1954–61, was significantly greater than the means for 1957 and 1959, and was slightly less than the means for 1958 and 1961 (fig. 9). Thus, although the mean annual sediment discharge (510,000 tons during the period of sediment investigations) probably significantly exceeded the long-term mean sediment discharge, the annual discharge-weighted sediment concentration (2,970 ppm) probably differed only slightly from the long-term weighted concentration. The high annual sediment discharge resulted from abnormally high water discharge, not from abnormally high sediment concentrations.

The annual sediment yield from the drainage area upstream from Deweese averaged about 450 tons per square mile during 1957–61. The actual source areas of the sediment obviously are not known. Large parts of the level loess plains contributed very little sediment to the Little Blue River, and some of the large poorly drained lagoons contributed no sediment to the stream. Some of the highly dissected valley-breaks areas and some areas of severe erosion probably contributed sediment at a rate of thousands of tons per square mile per year. Data on average annual sediment yield per square mile give no indication of the extreme variations with time and area that may be included in the computation of the average. In Little Blue River near Deweese, as in the entire Little Blue River basin, most of the suspended sediment is probably derived from a minor part of the total area during 10 percent or less of each year.

At Little Blue River near Fairbury (Endicott), sediment data were obtained only periodically (fig. 2). To supplement the data obtained by standard methods, stationary automatic samplers were used during many rises in stage during 1956–57. Computations were made of the average relation of sediment discharge to water discharge for the period of record and the average relation of sediment discharge (computed from data obtained by automatic samplers) to water discharge during major rises in stage during 1956–57 (fig. 16). The data show that for a given water discharge sediment discharge was markedly higher during the rising stage than during the entire period of high stage. Because suspended-sediment concentrations are commonly much higher during the rising stage than during the falling stage, most of the suspended-sediment during any given rise may be discharged before peak stage, although most of the water is discharged after peak stage.

Estimates based on a long-term flow-duration curve and on a "sediment rating curve" prepared from periodic data indicate that the long-term average annual sediment discharge at the Little Blue River near Fairbury is about 1.2 million tons. Thus, the estimates of sediment discharge for the sites near Deweese and near Fairbury indicate that although the drainage area near Fairbury is only about twice that near Deweese, the sediment discharge near Fairbury is about triple that near Deweese. Computations indicate that the annual discharge-weighted suspended-sediment concentrations are similar for both sites. Thus, the disproportionately high sediment discharge near Fairbury is caused mainly by the greater runoff from the middle third of the basin than from the upstream third of the basin. A main-stem reservoir that regulated flow and trapped 95 percent of the sediment from the upstream third of the basin probably would cause a reduction in the sediment discharge near Fairbury. This reduction, however, could be significantly less than the amount of sediment trapped in the reservoir if the regulation of flow resulted in net degradation in the channel between the reservoir and Fairbury.

Suspended-sediment discharge data were obtained at Waterville, Kans., by the Corps of Engineers (Kansas City District) during the 1960–62 water years. Although runoff from snow melt during March 1960 caused main-stem streamflow to be much greater than normal during 1960, precipitation and runoff data (fig. 9) suggest that the sediment data obtained at Waterville during 1960–62 may be fairly representative of long-term conditions. For example, during 1961, streamflow was slightly less than normal from Deweese, was about normal near Fairbury, and was appreciably greater than normal at Waterville; and during 1962, streamflow was appreciably greater than normal near Deweese, was slightly greater than normal near Fairbury, and was slightly less than normal at Waterville. If the relation of sediment discharge to water discharge at Waterville (fig. 16) is assumed to be representative of long-term conditions, the average annual sediment discharge at Waterville, computed from this relation and from flow-duration data (fig. 10), is about 1.9 million tons.

The part of each sediment rating curve (fig. 16) that represents water discharges equaled or exceeded less than 3 percent of the time is of unknown reliability. Few data are available to define this part, which represents a small percentage of the time but which has a significant effect on the computed long-term sediment discharge. The values in table 1 were computed mainly from sediment rating curves and flow-duration data and are a reasonable approximation of the sediment-discharge characteristics of the Little Blue River; the values are reliable to the extent that the sediment data obtained during the short periods of investigation are representative.

TABLE 1.—*Summary of streamflow and suspended-sediment data for the Little Blue River*

	Near Deweese	Near Fairbury [1]	At Waterville [2]
Drainage area:			
Square miles	1,140	2,320	3,330
Percentage of drainage area at Waterville	34	70	
Suspended sediment:			
Estimated long-term average discharge ... tons per yr	400,000	1,200,000	1,900,000
Percentage of long-term average discharge at Waterville	21	63	
Yield ... tons per sq mi	350	520	570
Discharge-weighted concentration ... ppm	2,800	3,300	3,000
Streamflow:			
Long-term average ... cfs-days per yr	53,000	135,000	236,000
Percentage of long-term average at Waterville	24	63	

[1] Station location changed Sept. 25, 1957, from "near Endicott"; drainage area 2,340 sq mi.
[2] Station location changed Apr. 29, 1958; previous drainage area 3,440 sq mi.

PARTICLE-SIZE DISTRIBUTION OF THE SEDIMENT

SUSPENDED SEDIMENT

The size distribution of suspended-sediment particles in streams depends on the material available for transport and the flow characteristics of the stream. Although the particle-size distributions determined in the laboratory for sand and coarser particles represent fairly accurately the sizes actually transported by streams, the determinations for silt and clay are not necessarily representative. The dispersion by chemical (hydrogen peroxide and sodium hexametaphosphate) and mechanical means to which the silt and clay are subjected during preparation for analysis results in a suspension of discrete inorganic particles. In the natural stream, some of the silt and clay may be transported as aggregates of sand, and a significant part of the clay may be transported as aggregates of silt. The difference between the particle-size distribution of silt and clay that is determined in the laboratory and the particle-size distribution of the material in the natural stream depends on stream turbulence, chemical quality of the water, distance of transport, mineralogy of the sediment, and size and stability of the original aggregates; the difference cannot be evaluated quantitatively by present analytical methods. The percent of sand in suspension in the stream cannot be less than that shown by the analysis, the silt could be less or greater than that shown, and the clay is almost certainly less.

Particle-size analyses show that about 95 percent of the total annual suspended-sediment discharge of the Little Blue River near Deweese and near Fairbury is silt and clay. The percentage of each of the size fractions—sand, silt, and clay—is unrelated to sediment discharge or to water discharge. The percentage of clay, for example, generally was between 55 and 80 at water discharges that ranged from about 50 to 13,000 cfs (fig. 17).

The concentrations of sand, silt, and clay tend to increase with water discharge. The percentage of sand may decrease, however, while the concentration of sand increases; during periods of overland runoff, the quantities of silt and clay that enter the stream are much greater than the quantity of sand that enters the stream and remains in suspension. Percentages of sand, silt, and clay in suspended-sedimet samples obtained at discharges that ranged from about 50 to 12,500 cfs near Deweese and from about 100 to 13,000 cfs near Fairbury are shown in figure 18.

The chemical characteristics of the water in which the silt and clay are suspended has a significant effect on the results of a particle-size analysis. To investigate this effect, selected suspended-sediment samples were split; part of each sample was analyzed in distilled water to which chemical dispersants were added, and part was analyzed in untreated stream water. Such analyses of suspended sediment from the Little Blue River (table 2) typically show that under laboratory conditions, the percentage of clay is much less in stream water than in a dispersed suspension. The large differences in percentages for the 0.002 and for the 0.004 mm sizes are not due entirely to the flocculating power of the stream water. The dispersed suspension contains little or no organic matter, which was largely destroyed by treatment of the sediment with hydrogen peroxide; the stream-water suspension contains an unknown percentage of organic matter. The particle-size distribution in the stream-water suspension does not necessarily represent the particle-size distribution of the sediment in turbulent streamflow of identical chemical characteristics; and it does

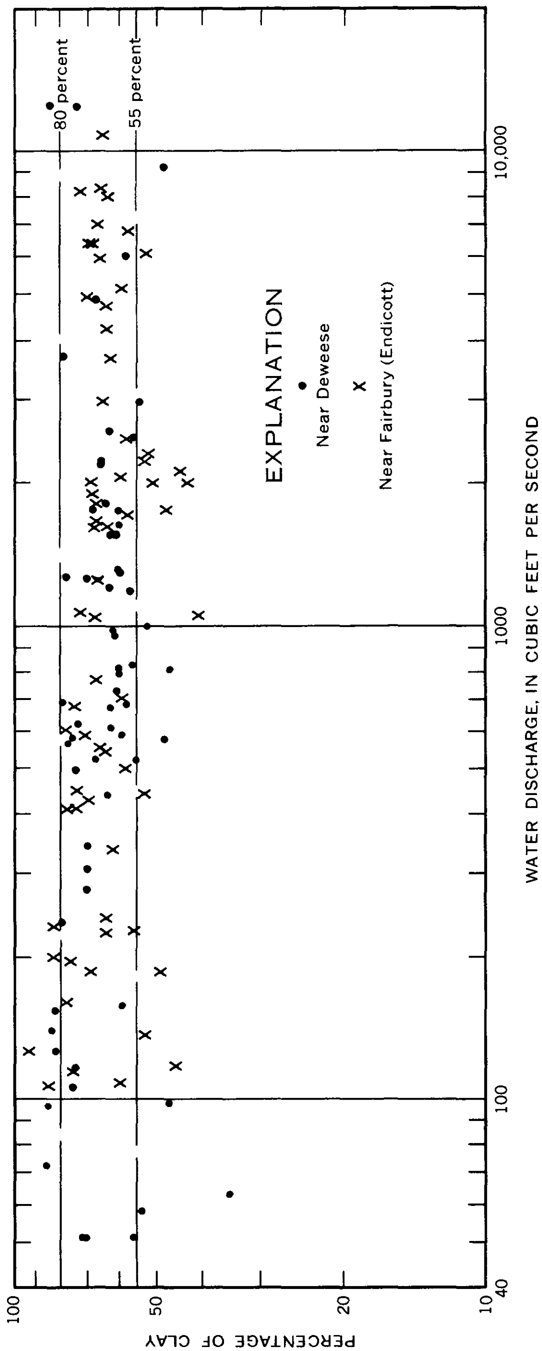

FIGURE 17.—Relation of percentage of clay in suspended sediment to water discharge, Little Blue River near Deweese and near Fairbury (Endicott).

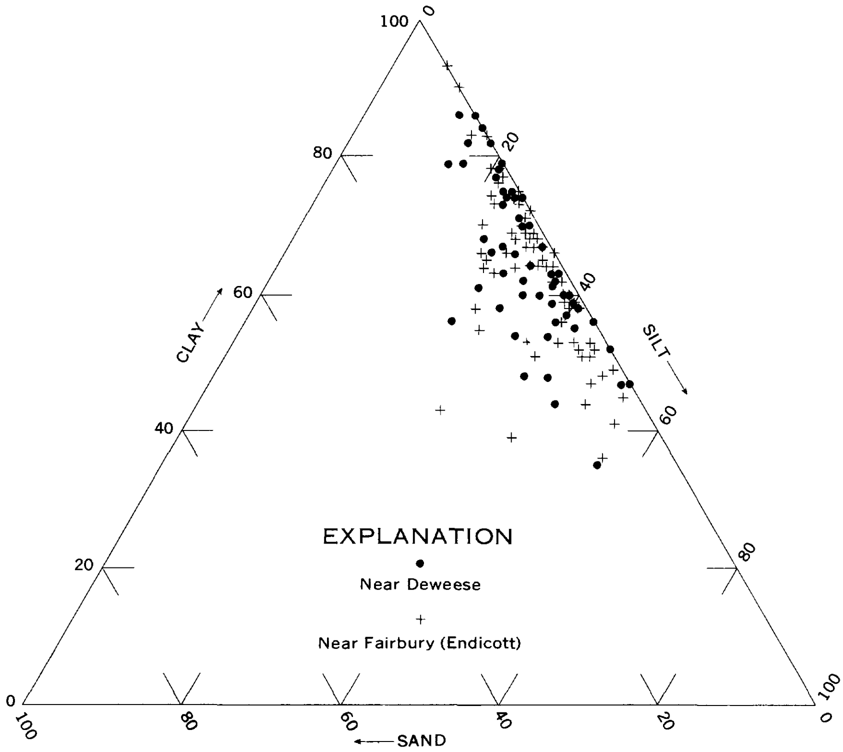

FIGURE 18.—Percentage of sand, silt, and clay in suspended sediment, Little Blue River near Deweese and near Fairbury (Endicott).

not necessarily represent the distribution under settling conditions that might exist in a large reservoir. The differences between the untreated and dispersed suspensions are only an indication that significant flocculation of sediment would occur in a reservoir if the inflowing sediment-water mixture were impounded for a period of time. Such flocculation would be expected, of course, in impounded water of the Little Blue River; the weighted-average dissolved-solids concentration for Little Blue River near Deweese is about 180 ppm, and calcium and magnesium are about 80 percent of the total cations. Nearly all the sediment that might be transported into a large reservoir on the Little Blue River would be deposited in the reservoir. The particle sizes of the deposited sediment would probably be different from the sizes determined by analysis in either a dispersed or an untreated suspension of sediment.

TABLE 2.—*Results of particle-size analyses of selected suspended-sediment samples from the Little Blue River*

Date	Water discharge (cfs)	Suspended sediment: Concentration (ppm)	Percent finer than indicated size (mm): 0.002	0.004	0.062	Methods of analysis
Near Deweese						
May 14, 1957	818	4,270	52	60	93	(1)
			34	49	93	(2)
Mar. 28, 1960	7,030	2,400	52	58	89	(1)
			25	44	89	(2)
Near Endicott						
Apr. 24, 1957	442	3,680	39	53	98	(1)
			17	30	98	(2)
May 17, 1957	1,540	4,420	55	62	98	(1)
			35	50	98	(2)

[1] Pipet method, distilled water, chemical and mechanical dispersion.
[2] Pipet method, stream water.

BED MATERIAL

Streambed material in the Little Blue River averages slightly finer near Deweese than near Fairbury (Endicott); the median particle size was about 0.73 mm near Deweese and about 0.77 mm near Fairbury (Endicott). During 1955–61, bed material samples were obtained near Deweese at a total of about 460 points in the bed on 48 different days, and near Fairbury (Endicott) at a total of about 360 points on 34 different days. Average particle size of the material was similar for each size range at both sites. For example, near Deweese 8 percent of the material was finer than 0.25 mm, 38 percent finer than 0.50 mm, and 81 percent finer than 2.0 mm; near Fairbury (Endicott), 7 percent was finer than 0.25, 36 percent finer than 0.50, and 79 percent finer than 2.0 mm.

The similarity in particle size of bed material (fig. 19) probably is due to the similarity in the source of the material in long reaches of the river. Much of the material probably is from the fluvial sand and gravel of Pleistocene age, which are exposed in many places in the channel and are the main source of the ground water that maintains the perennial flow in the Little Blue River.

Study of the particle-size data on suspended sediment and bed material indicates that very little material of the bed-material sizes is present in suspended sediment. About 98 percent of the total annual suspended-sediment discharge is finer than 0.125 mm near Deweese and near Fairbury (Endicott). The average particle-size distributions of all bed material samples collected show that none of the bed material is finer than 0.125 mm.

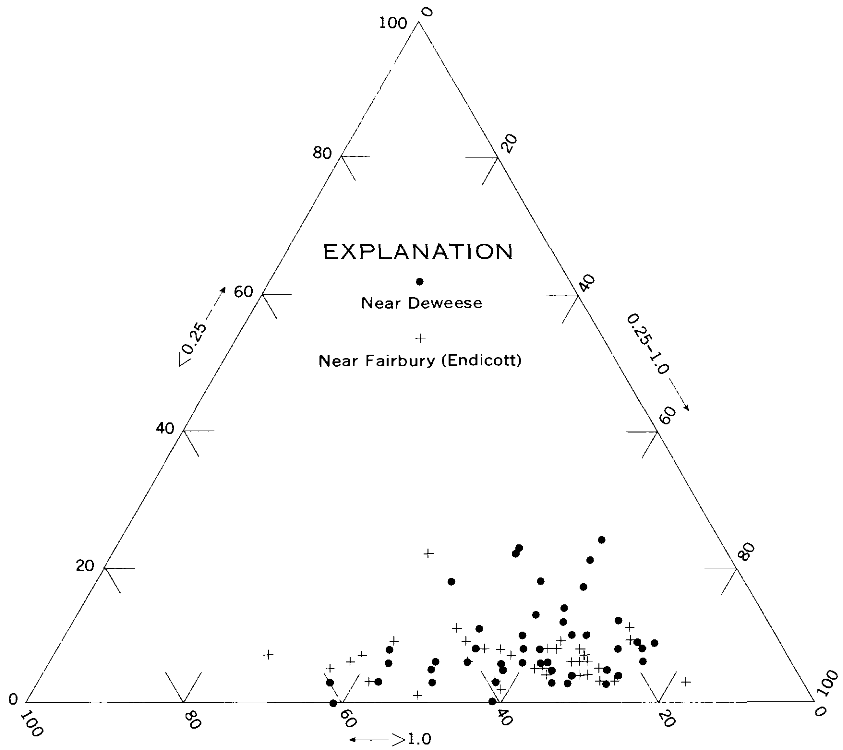

FIGURE 19.—Percentages of selected size ranges of bed material. Little Blue River near Deweese and near Fairbury (Endicott).

TOTAL SEDIMENT DISCHARGE

Total sediment discharge consists of the measured suspended-sediment discharge and the unmeasured discharge. The latter includes all sediment that moves along the streambed; it may also include some suspended sediment near the streambed. The hydraulic conditions prevailing in the Little Blue River result in minor movement of the coarse streambed material and in suspension of almost none of the particles of the streambed.

Total sediment discharge of a stream can be computed from data on concentration and particle size of suspended sediment, particle size of bed material, hydraulic measurements, and water temperature (Colby and Hubbell, 1961). Reliable results are obtained only if one or more of the size ranges of suspended sand also are present in the bed sand. The necessary overlap of sizes of suspended sediment and of bed material is not common in the Little Blue River. A few computations of the total sediment discharge near Deweese indicate that suspended-sediment discharge is 95 percent or more of the total sediment discharge over a wide range of water discharge. Also, the suspended silt and clay generally is 90 percent or more of the total sediment discharge.

CHEMICAL QUALITY OF THE WATER

The types and concentrations of dissolved minerals in water at a given time and place are governed by the chemical composition of any material with which the water has come into contact. While condensing and falling, atmospheric precipitation dissolves not only atmospheric gases (nitrogen, oxygen, and carbon dioxide) but also airborne minerals such as chlorides and sulfates of sodium and magnesium derived from the earth. These dissolved atmospheric constituents and the type and solubility of the minerals in soil and rocks determine the reactions that occur when rain touches the earth's surface. The dissolved-solids content of water is affected also by the length of time that water is in contact with the minerals, by evapotranspiration, and by industrial, agricultural, and municipal effluents. Water that travels overland commonly has less contact with soluble minerals and contains less dissolved solids than water that infiltrates to the zone of saturation below the earth's surface and then slowly percolates laterally toward places of exit at the land surface. If overland runoff is impounded for long periods, however, evaporation of the water may result in substantial increases in dissolved-solids concentrations.

Water samples from the Little Blue River near Deweese and near Endicott were analyzed by the methods described by Rainwater and Thatcher (1960). Similar methods were used by the Kansas State Board of Health for analysis of samples collected at Waterville.

CHEMICAL CHARACTERISTICS

The chemical characteristics of the streamflow are determined largely by the proportion of ground water that enters the streams of the drainage basin. The base flow of the Little Blue River is sustained by the discharge of ground water into the river channel and into the channels of the creeks tributary to it. Such discharge occurs only where channels are incised below the water table, or upper surface of the zone of saturation. According to Johnson (1960, p. 1), part of the ground water that is discharged into the Little Blue drainage system is derived from underflow that originates outside the drainage basin and part from precipitation within the basin area.

In the upstream half of the basin, large amounts of ground water from deposits of Pleistocene age are used for irrigation. Because most of the irrigated soils are permeable, the excess applied water either evaporates or percolates back to the zone of saturation. Very little irrigation runoff enters the Little Blue River directly.

Owing to the calcareous nature of both the soils and the thick loess that overlie the aquifers in much of the basin, most ground water and surface water is of the calcium bicarbonate type. A typical analysis of ground water from fluvial deposits of Pleistocene age near the headwaters of the Little Blue River indicates a chemical composition similar to that of the base flow of Little Blue River near Deweese (fig. 20); both are of the calcium bicarbonate type. Nearly all ground water in the basin above Fairbury has a low and uniform dissolved-solids content. A few analyses, however, show waters that have a dissolved-solids content of 700 to 1200 ppm and that are of the calcium sulfate type; such analyses probably represent water from Cretaceous bedrock or mixed waters from aquifers of Pleistocene and Cretaceous age.

The relation of concentrations of some constituents, and hardness, to water discharges at Little Blue River near Deweese is shown in figure 21. The vertical distance from one curve to a succeeding one represents the concentration, in parts per million, of the indicated constituent, or the hardness, for a particular discharge. The concentrations of the chemical constituents for low discharges (<100 cfs) are generally representative of the base flow, and those for high discharges (>1,000 cfs) are representative of flows consisting mostly of overland runoff.

Although the overland flow has only one-third the dissolved-solids content of the base flow at Deweese, brief but intense thunderstorms cause a large percentage of the total annual water and salt discharge to occur during relatively short periods. Flows less than 100 cfs occur 80 percent of the time but account for only 38 percent of the total water discharge and 55 percent of the total salt discharge; flows from 100 to 1,000 cfs occur 18 percent of the time and account for 31 percent of the water discharge and 30 percent of the salt discharge; and flows greater than 1,000 cfs occur 2 percent of the time and account for 31 percent of the water discharge and 15 percent of the salt discharge.

Calcium and bicarbonate are the predominant chemical constituents of both the base flow and the overland flow near Deweese. Potassium, chloride, and sulfate account for most of the small chemical differences between the base and the overland flow. The concentration of potassium is higher in the overland runoff, and chloride is nearly absent (<1 ppm) from the overland runoff. The sulfate concentration is higher, in percentage of equivalents per million, in the overland than in the base flow. The observed silica concentration ranges from 39 ppm in the base flow to 10 ppm in the overland runoff.

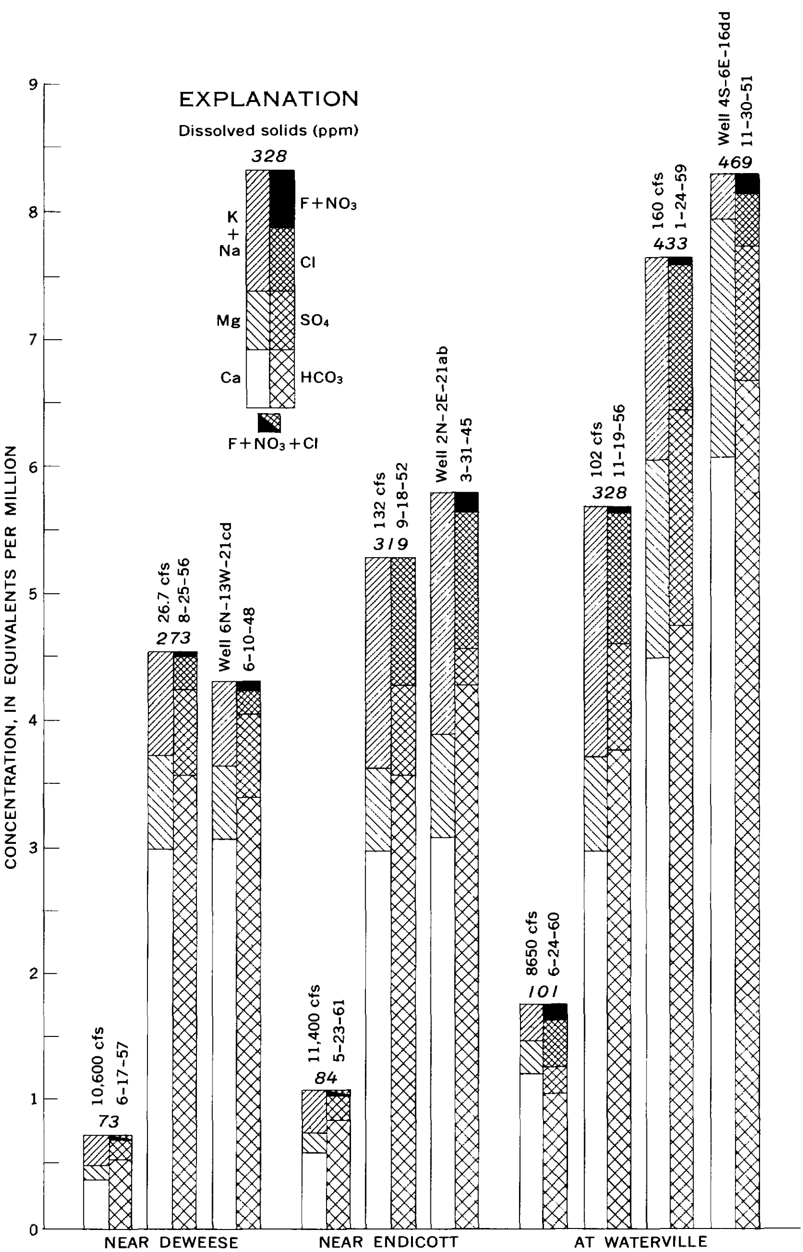

FIGURE 20.—Quality of ground water in selected wells and of surface water at high and low discharges, Little Blue River near Deweese, near Endicott, and at Waterville.

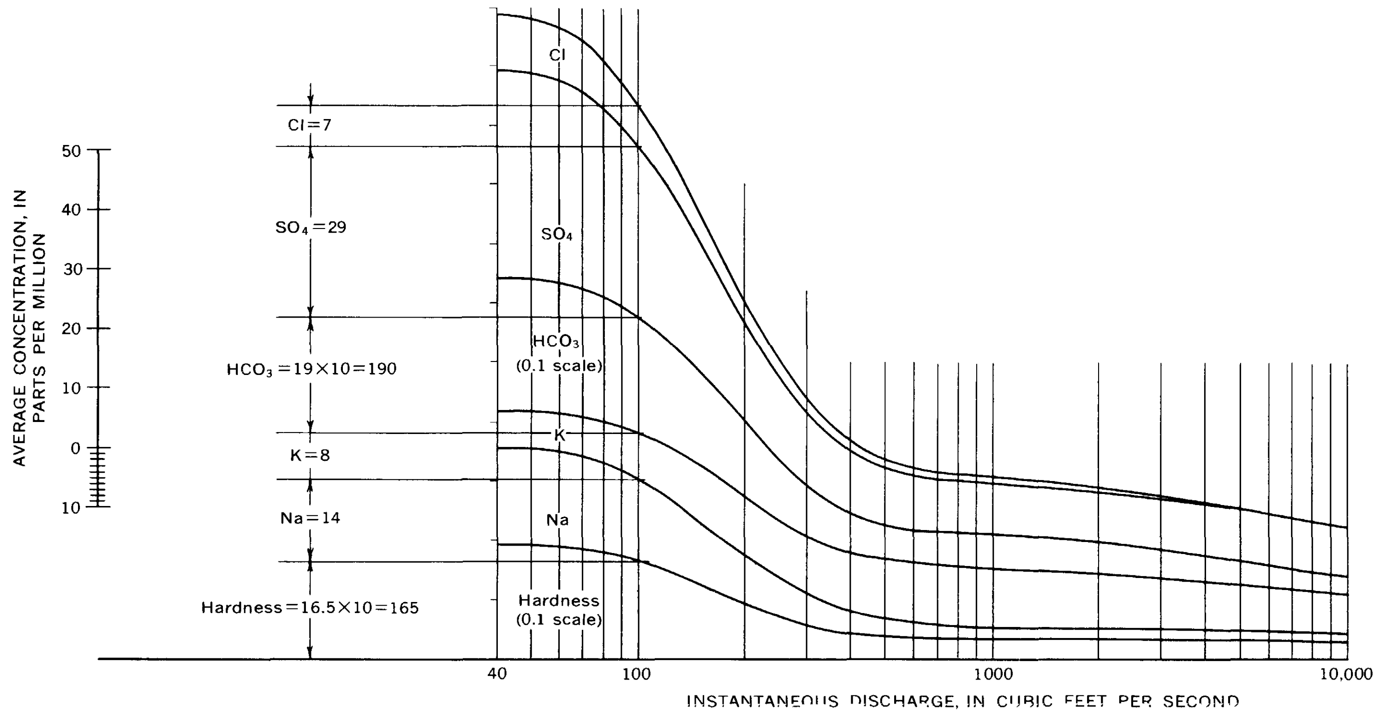

FIGURE 21.—Relation of selected chemical constituents and hardness to water discharge, Little Blue River near Deweese. The following example of interpretation of graph is illustrated at the left of the figure: At a discharge of 100 cfs, the concentrations (in parts per million) of some constituents and the hardness are Cl, 7; SO_4, 29; HCO_3, 190; K, 8; Na, 14; and hardness, 165.

Figure 22 shows the relation of weighted-average concentrations of different ions to different proportions of base and overland flow near Deweese for years of low (1956) and high (1960) runoff and for the period of record (1954–62). The weighted averages were computed

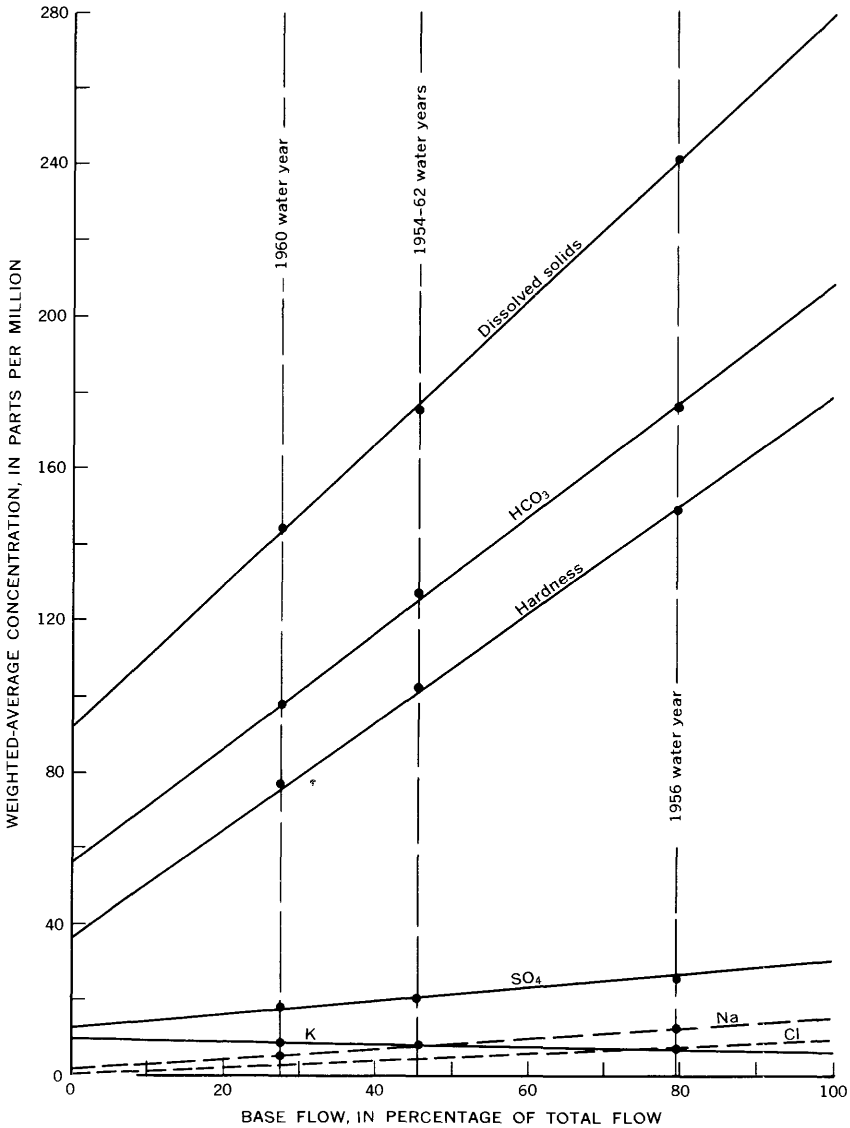

FIGURE 22.—Relation of weighted-average concentrations of chemical constituents to different proportions of base and overland flow, Little Blue River near Deweese, 1956, 1960, 1954–62.

from figure 21 and flow-duration data. As the percentage of base flow increases or decreases, the weighted-average concentrations increase or decrease respectively. The weighted averages represent the theoretical chemical composition of the water if the entire flow for the period were impounded in a reservoir. Although evaporation from a reservoir can be significant and thereby alter the composition of the water, releases and seepage from the reservoir probably would prevent an appreciable increase in dissolved solids except during a prolonged drought. During a year of high runoff, such as 1960, not all the water would be impounded; nevertheless, any combined proportions of base and overland flow would be suitable for irrigation.

Return flows from lands irrigated with the reservoir water would be small, if any, and should not have a significant effect upon the chemical quality of the Little Blue River.

The Little Blue River near Endicott is near the western boundary of the glacial till area. Most of the base flow at Endicott is from the fluvial deposits of Pleistocene age in the upstream two-thirds of the basin. Outflow of water from the Dakota Sandstone, however, influences the chemical quality of the stream near Fairbury. Analysis of the chemical quality of the ground water in the alluvial deposits along Big Sandy Creek and the Little Blue River above Fairbury suggests that the greater dissolved-solids content of the base flow near Endicott probably is due to the effect of the Dakota Sandstone in the reach from Fairbury to Endicott. The chemical composition of the water from a flowing well in the alluvium near Fairbury (fig. 20) is almost the same as the base flow near Endicott. Both are the calcium bicarbonate type, and their dissolved-solids content is similar.

The average dissolved solids of the base flow was approximately 70 ppm higher near Endicott than near Deweese (table 3). Sodium and chloride accounted for most of the increase, whereas the concentrations of calcium, magnesium, bicarbonate and sulfate remained about the same. The overland flow near Endicott has slightly higher dissolved-solids content than that near Deweese. Silica ranged from 28 ppm in low flow to 11 ppm in high flow.

TABLE 3.—*Average concentrations of selected chemical constituents and of hardness in the Little Blue River, in parts per million*

	Near Deweese		Near Endicott	
	Base flow	Overland flow	Base flow	Overland flow
Sodium plus potassium (Na+K)	22	9	38	9
Bicarbonate (HCO_3)	220	40	220	60
Sulfate (SO_4)	33	8	36	9
Chloride (Cl)	9	0	38	2
Dissolved solids (residue on evaporation at 180°C)	280	80	350	90
Hardness (as $CaCO_3$)	185	30	185	45

Calculations based on the dissolved-solids concentrations for Deweese and Endicott indicate that the dissolved solids in the base flow probably would increase at Endicott if a reservoir were constructed near Deweese and all upstream base flow were withheld. The mean annual base flow and dissolved-solids concentration for the period 1954–62 were 89,150 acre-feet and 350 ppm at Endicott and 49,380 acre-feet and 280 ppm at Deweese. If it is assumed that no releases were made from the dam and that the chemical quality of the ground-water effluent between Deweese and Endicott was unaffected by the reservoir water, the dissolved-solids concentration of the base flow will be

$$\frac{(89{,}150)\,(350)-(49{,}380)\,(280)}{39{,}770}=437 \text{ ppm.}$$

Thus, a main-stem reservoir near Deweese could result in a dissolved-solids increase of about 90 ppm near Endicott. However, sufficient releases of the impounded water could improve the chemical quality of the low flow in downstream reaches.

The mineral content of ground water in the lower third of the basin is considerably higher than in the upper two-thirds and varies with the water-bearing formation. Most of the ground water is of the calcium bicarbonate type, but high concentrations of sodium, chloride, and sulfate are common. An analysis of water from the alluvium near Waterville shows that it is the calcium bicarbonate type and has a dissolved-solids concentration of 469 ppm (fig. 20).

During periods of prolonged drought most of the base flow at Waterville is derived from the Pleistocene aquifers upstream from Endicott; during periods of normal or above-normal precipitation there is a higher percentage of base runoff in the reach from Endicott to Waterville. Owing to the drought conditions existing prior to 1958, the dissolved solids and chemical composition of the low flows at Waterville were nearly the same as at Endicott. Beginning in 1958, there was a higher percentage of gain in low flow in this reach and the dissolved solids increased (fig. 23).

During November 1956, the mean daily flow was 117 cfs at Endicott and 104 cfs at Waterville. The depletion indicates there was little, if any, ground-water discharge between Fairbury and Waterville during that month. The dissolved-solids concentration at Waterville for a low flow (102 cfs) on November 19 was 328 ppm (fig. 20), and the chemical quality was similar to the chemical quality during low flow at Endicott. The discharge at Endicott on the same day was 129 cfs, or 27 cfs more than at Waterville.

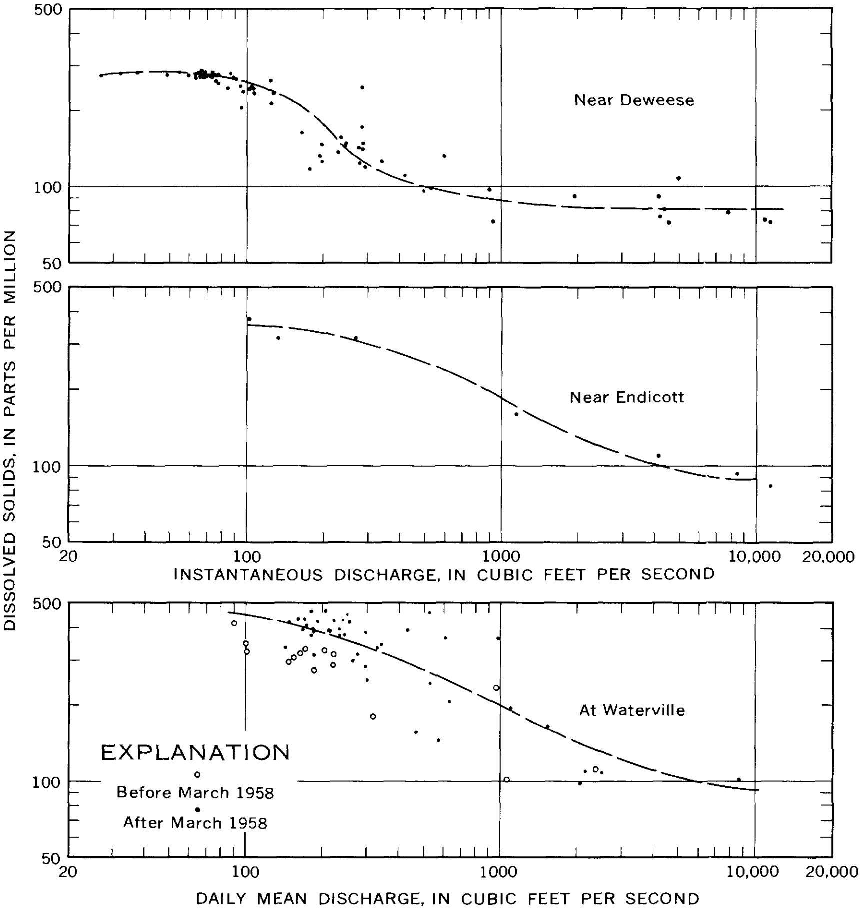

FIGURE 23.—Relation of dissolved solids to water discharge for Little Blue River near Deweese, near Endicott, and at Waterville.

After 3 years of normal or above-normal precipitation, the dissolved-solids concentration for a low flow (160 cfs) at Waterville was 433 ppm. The discharge at Endicott on the same day was 112 cfs, or 48 cfs less than at Waterville. The increase of about 80 ppm in dissolved-solids content was due to the higher concentrations of calcium, bicarbonate, and sulfate in the ground-water effluent between Endicott and Waterville.

Before the closing of Tuttle Creek Dam on the Big Blue River in 1961, the mean annual discharge of the Little Blue River at Waterville (drainage area 3,440 sq mi) was 38 percent of the mean annual discharge of the Big Blue River at Randolph (drainage area, 9,100 sq mi); Randolph is a few miles downstream from the confluence of the

Big and Little Blue Rivers. The chemical quality of the Big Blue River at Schroyer, a few miles upstream from the confluence, is similar to that of the Little Blue River at Waterville. For the Big Blue River, the dissolved solids ranged from 52 ppm at high discharge to 479 ppm at low discharge; and for the Little Blue River, from 101 ppm at high discharge to 469 ppm at low discharge. Inflow to the Tuttle Creek Reservoir from the Little Blue River probably has a somewhat higher average dissolved-solids content than that from the Big Blue River because a larger percentage of the mean annual discharge of the Little Blue River is due to ground-water effluent. Water in the reservoir should be low in dissolved solids because the dilute overland flow contributes 70–90 percent of the mean annual discharges of both rivers.

SUITABILITY FOR USE

IRRIGATION

Most of the irrigable land in the Little Blue River basin is upstream from Endicott. Currently (1965), ground water is used for nearly all irrigation within the basin, but the Little Blue River could be a dependable water supply for irrigation of the bottom lands along the river. If a reservoir is constructed near Deweese, it could supply water for some of the uplands near Ruskin and Gladstone where sufficient ground water for irrigation is not available.

The suitability of water for irrigation depends primarily upon the total salt concentration (salinity), the relative proportion and concentration of some of the constituents, and the characteristics of the soil upon which it is to be applied. Continued use of water having a high dissolved-solids content can cause soils to become saline. Although calcium and magnesium help maintain favorable soil structure and permeability, relatively high concentrations of sodium can adversely affect the soils by replacing calcium and magnesium on the exchange complex and thereby causing a loss of permeability and productivity. Residual sodium carbonate and alkali soils may result when concentrations of bicarbonate appreciably exceed that of calcium and magnesium. Boron, a minor constituent of most waters, is essential to plant growth but can be harmful if the concentration exceeds the limits of tolerance of the plant.

During low flow, the dissolved-solids content of Little Blue River water is about 280 ppm near Deweese and 350 ppm near Endicott. Although the greater dissolved solids content near Endicott is caused mainly by an increase in sodium, the water remains suitable for irrigation. The percent sodium generally ranges from 13 to 15 at Deweese and from 29 to 31 near Endicott. Near Deweese and near Endicott, equivalents per million of calcium and magnesium either equal or exceed that of bicarbonate and as a result residual sodium carbonate should not be a hazard. Boron does not exceed the limits of tolerance of the most sensitive crops; the maximum observed boron concentration was 0.13 ppm at Deweese.

The weighted averages for the period of record (1954–62) (fig. 22) indicate that the dissolved-solids concentration of water impounded in a reservoir near Deweese would be approximately 180 ppm, which would be less than that of most of the ground water now used successfully for irrigation in the basin. Generally, the larger the proportion of reservoir water the more suitable the water would be for irrigation.

Most of the irrigable lands near Ruskin and Gladstone that would be supplied water from a reservoir near Deweese are of the Crete soil series. They have good drainage characteristics and, if proper irrigation practices are observed, harmful concentrations of salts or alkali conditions should not develop.

DOMESTIC

Although water from the Little Blue River is not currently used for domestic or industrial purposes, increased urban or industrial growth of towns and communities along the river could result in a use for such purposes. Upstream from Endicott the chemical quality is suitable for domestic and industrial use, but near Waterville, treatment may be needed for excessive iron, manganese, and hardness. At this downstream point, observed concentrations of iron plus manganese exceeded the recommended maximum of 0.3 ppm; such concentrations of iron and manganese may cause staining of laundry and give an objectionable taste to the water. Downstream from Endicott the water may also need softening for some purposes; the observed hardness generally ranged from 200 to 300 ppm at Waterville.

Sewage effluent at Hebron and Fairbury is discharged into the Little Blue River. During normal flow, the effluent is insufficient to affect significantly the chemical quality downstream from these towns. Extremely low flow and increased sewage discharge could cause pollution between Hebron and the confluence with Big Sandy Creek and below Fairbury. Because the Big Sandy contributes appreciable flow to the Little Blue River, pollution should not be a problem between the confluence and Fairbury.

CONCLUSIONS

Water-quality investigations made discontinuously during 1951–63 at five different sites on the Little Blue River have resulted in the following conclusions:

1. The estimated long-term sediment discharge at Little Blue River near Deweese is about 400,000 tons per year; near Fairbury, about 1,200,000 tons per year; and at Waterville, about 1,900,000 tons per year.
2. Nearly all the suspended sediment is silt and clay. The streambed material is mainly medium sand to gravel.
3. Suspended-sediment discharge is 95 percent or more of the total sediment discharge over a wide range of water discharge.
4. Water-utilization problems resulting from high suspended-sediment concentrations are not significant in the basin; use of water directly from the Little Blue River is quantitatively negligible.
5. The overland runoff and the base runoff throughout the Little Blue River basin are of the calcium bicarbonate type.
6. During flows representative of base runoff, the dissolved solids near Deweese, near Endicott, and at Waterville were 273, 319, and 433 ppm, respectively; during flows representative of overland runoff, the dissolved solids were 73, 84, and 101 ppm.
7. The chemical quality of both base runoff and overland runoff is suitable for irrigation.

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