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Sediment Characteristics of Tennessee Streams and Reservoirs

Prepared by

U.S. GEOLOGICAL SURVEY

in cooperation with

TENNESSEE DEPARTMENT
OF
HEALTH AND ENVIRONMENT

UNITED STATES
DEPARTMENT OF THE INTERIOR
GEOLOGICAL SURVEY

SEDIMENT CHARACTERISTICS OF TENNESSEE STREAMS AND RESERVOIRS

Stanley W. Trimble and William P. Carey

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WILLIAM P. CLARK, Secretary

GEOLOGICAL SURVEY

Dallas L. Peck, Director

For additional information write to:

District Chief
U.S. Geological survey
A-413 Federal Bldg.
U.S. Courthouse
Nashville, TN 37203

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CONVERSION FACTORS

For use of readers who prefer to use metric units, conversion factors for terms used in this report are listed below:

Multiply	By	To obtain
acre-foot (acre-ft)	1234	cubic meter (m^3)
foot (ft)	0.3048	meter (m)
mile (mi)	1.609	kilometer (km)
pound (lb)	0.4536	kilogram (kg)
ton, short	0.9078	megagrams (Mg)
cubic foot per second (ft^3/s)	0.02832	cubic meter per second (m^3/s)

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ABSTRACT

Suspended-sediment and reservoir sedimentation data have been analyzed to determine sediment yields and transport characteristics of Tennessee streams. Data from 31 reservoirs plus suspended-sediment data from TVA sampling efforts in the 1930's and 1960's, and U.S. Geological Survey efforts from 1975-82 have been used.

Results of the analyses show that the measured suspended-sediment is mostly silt and clay-size material even in the sand bed channels of western Tennessee. Samples of suspended sediment rarely exceed 25 percent sand. Computed unmeasured load is less than 10 percent of the total sediment load in western Tennessee. Unmeasured load has not been computed for middle and eastern Tennessee streams because the bed material is generally coarse and quite variable. However, unmeasured load in these streams is believed to be less than 5 percent of total load. Transport curves show that when flow is less than about 1 cubic foot per second per square mile, western Tennessee streams have higher concentrations than middle or eastern streams. When flow exceeds about 10 cubic feet per second per square mile, however, concentrations in middle and eastern streams can equal or exceed those in western streams. The more efficient sediment-delivery processes operating in middle and eastern Tennessee basins are responsible for the rapid increases in suspended sediment concentrations with increasing flow.

Sediment yields for middle and eastern Tennessee basins generally are less than 800 tons per square mile per year, however, heavily strip-mined basins can have yields from 1,000 to 3,000 tons per square mile per year. Yields for the heavily agricultural and channelized basins of western Tennessee generally range from 700 to 1,000 tons per square mile per year.

INTRODUCTION

In 1979, the U.S. Geological Survey in cooperation with the Tennessee Department of Health and Environment, established a statewide network of 30 suspended-sediment sampling stations to provide information on suspended-sediment yields and transport characteristics of streams throughout the State. All of the sediment stations were located at existing stream gaging stations.

Suspended-sediment samples were collected at each station approximately once every 6 weeks. Funding was not available for intensive sampling during storm periods. However, some high flow samples were collected during special trips made for water discharge measuring purposes.

In addition to the suspended-sediment data collected specifically for this project, information on sediment accumulation at 31 reservoirs plus suspended-sediment data from Tennessee Valley Authority (TVA) sampling efforts in the 1930's and 1960's and U.S. Geological Survey efforts from 1975-82 have been used. By including these suspended-sediment data, the number of sampling sites analyzed for this report increased from 30 to 42.

Description of Additional Data

Sediment accumulation data from reservoir surveys are available for several impoundments on the Cumberland and Tennessee Rivers. There are nine major reservoirs in the Cumberland River basin with design storage capacities greater than 75,000 acre-feet. Seven of these reservoirs drain areas in Tennessee, but only two of the seven have sufficient information for sediment-yield computations. In the Tennessee River basin, there are 22 major impoundments that have sufficient data for sediment-yield computations. In addition, there are five smaller reservoirs that have contributing drainage areas greater than 50 square miles and have sufficient data for sediment-yield computations. Although the Tennessee River basin extends partially into surrounding states, the reservoir sediment data from the whole basin have been analyzed and are presented in this report.

In addition to the reservoir data, there is also a considerable amount of measured suspended-sediment data available for the Tennessee River basin. The TVA has conducted two suspended-sediment investigations in the Tennessee basin. The first investigation was conducted from 1934 to 1942 and consisted of a comprehensive sampling effort on numerous major tributaries and on the main stem of the Tennessee River. The purpose of that study was to gather information which would aid in the planning of a reservoir system for the valley. Suspended-sediment sampling stations were established at 48 locations on the Tennessee River and its tributaries. Data were collected for at least 3 years at each station with the most intensive data collection occurring between 1935 and 1937. Daily sediment discharge has been computed by TVA for the intensive data collection period.

The second TVA study began in 1962 and lasted for 3 years. The purpose of that investigation was to compare suspended-sediment yields with the results of the first study. During the second study, many of the original sampling stations were downstream from impoundments and therefore could not be used for comparison. Ten of the original 48 stations were on unregulated streams and these stations were used in the comparison study. Data from both TVA studies have been incorporated into the present study of sediment yields in Tennessee. Although the data collection period of these two studies is short, the full range of discharge occurring during the period was sampled.

Information on suspended-sediment yields is very sparse in that part of the State west of the Tennessee River divide. This area of the State, commonly referred to as western Tennessee, is heavily agricultural and geologically consists of unconsolidated gravel, sand, silt, clay, and loess deposits. Much has been written about severe erosion and soil loss in this area; however, little effort has been expended in collecting sediment-yield data to actually quantify the amount of material being delivered to the drainage network. Because there are no major reservoirs located in western Tennessee, data from two reservoirs in northern Mississippi and data from two sediment sampling stations in western Tennessee with more than 3 years record were analyzed along with the data collected in this study.

Acknowledgments

The authors thank Mr. William McMaster and the Data Services Branch staff at TVA for their assistance in providing us with access to the archived TVA sediment data.

METHODS OF ANALYSIS

Reservoir Data

Large reservoirs make excellent sediment traps because quiescent waters allow nearly all of the stream's sediment load to settle out. The Tennessee Valley Authority, the U.S. Army Corps of Engineers, and the U.S. Department of Agriculture (USDA), Soil Conservation Service (SCS) have supplied useful data on reservoir deposition. Most reservoir survey data are published every 5 years by the U.S. Department of Agriculture with the most recent available for this study being data obtained through 1975 (Dendy and Champion, 1978a).

Reservoir data have decided advantages and problems as compared to using suspended-sediment data for calculating sediment yields. The advantages of using reservoir data are:

1. Suspended load samplers cannot get closer than about 3 inches to the streambed, thus the part of the total sediment load transported in this unsampled zone does not get measured. Because most of this material is coarse, reservoirs with high trap efficiencies trap essentially all of this normally unmeasured load.

2. Most of a stream's annual sediment load is transported during high-flow events which only occur a small percentage of the time. If these critical high flows are not sampled for suspended sediment, the resulting sediment-yield estimates may be significantly in error. Reservoirs intercept all flow events moving down the channel and thus trap some percentage of the sediment being transported by every flow event.

Use of reservoir data also has the following disadvantages:

1. Trap efficiency, the part of incoming sediment impounded by the reservoir, is difficult to determine and is probably the greatest element of uncertainty. Although methods are available to estimate average trap efficiency, trap efficiency of a reservoir is expected to change with stream discharge, sediment characteristics, water temperature, and reservoir operation. Especially troublesome are density currents which, under certain conditions of water temperatures and water release from the reservoir, allow direct passage of sediment through the reservoir. A density current is a highly turbid and relatively dense current which usually moves along the bottom of a body of standing water (USGS-OWOC, 1977). The relatively higher density can be caused by suspended sediment, dissolved solids, or temperature differences. Density currents exist in some TVA reservoirs, but data available are inadequate to determine their significance (Fry and others, 1953).

2. Bulk densities of reservoir sediment are difficult to ascertain, especially in reservoirs with considerable drawdown, where some sediment is dried periodically

and thereby compacted. Such dried sediment may have bulk densities twice that of submerged sediment. Bulk densities used in this study were furnished by the surveying agency but many of them were clearly estimates.

3. Reservoirs affect downstream sediment movement in a nondeterministic manner when their trap efficiencies are uncertain or highly variable. In order to obtain local sediment yields for a particular reservoir drainage area, the sediment outflow from the upstream reservoir must be subtracted from the total sediment collected during the same time period. A reservoir with a large gross drainage area, but with another large reservoir a short distance upstream, provides a particular problem because the net contributing drainage area is small and the potential for error is great. Sediment routing procedures through a series of reservoirs are discussed later in this report.

4. The measurement of sediment accumulation in reservoirs also presents problems. Resurveys are usually done by surveying cross-sectional profiles some distance apart. Each range is assumed to be a representative sample of a zone, and any lack of representativeness presents an error. The affect of above-crest or delta deposits is also uncertain because it is sometimes difficult to tell where reservoir-induced deposits end and where recent vertical accretion on the flood plains begins.

5. Reservoir sediment data define total yields but do not define the sediment transport dynamics of the inflowing system.

6. Shore erosion may add sediment to the pool. This volume is not always measurable and thus adds uncertainty. For example, the fines may be eroded from the pore space in gravel-rocky soil with little degradation on the banks and thus cause notable accumulation in the deeper part of the reservoir. Wave action primarily affects above-crest areas, but such areas are not always included in reservoir sediment surveys.

Despite the difficulties cited above, reservoirs with high trap efficiencies probably give the best long-term sediment-yield data available. This assumes that both the reservoir and the bulk density of sediment have been properly measured. Reservoir surveys are discussed in detail by Borland (1971).

Methods of Calculating Trap Efficiency

Estimating trap efficiency (TE) is the greatest problem in sediment-yield analysis from reservoir data. Trap efficiency is defined as the percentage of inflowing sediment that is retained in the reservoir (Vanoni, 1975). There are two basic methods for estimating TE, the Brune method and the Churchill method (Borland, 1971).

1. For the Brune method, the reservoir capacity is divided by the average annual inflow, the result being the retention time. This numerical index is then related to trap efficiency (fig. 1a).

2. The Churchill method, like the Brune method, uses the retention time, but that value is divided by the average velocity of water in the reservoir, a function of reservoir shape. The result is Churchill's sedimentation index which is related to

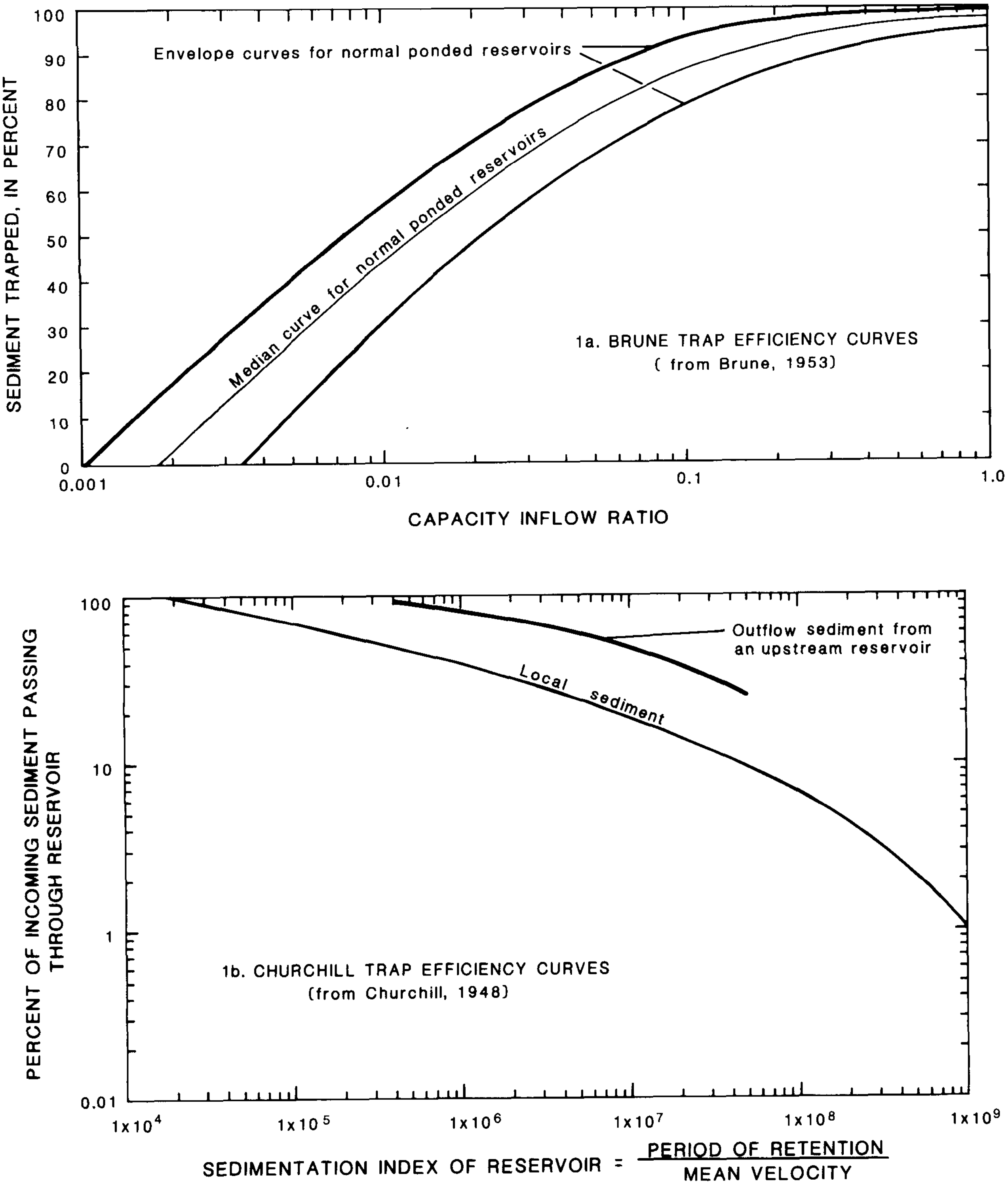


Figure 1.--Trap efficiency curves.

trap efficiency. The Churchill method accounts for both local sediment and sediment discharged from an upstream reservoir. Sediment that is discharged by an upstream reservoir will be referred to as outflow sediment. Local sediment is sediment that has been delivered to the reservoir from the contributing drainage area. Churchill's data were taken from TVA reservoirs and thus his procedure is especially appropriate to this study.

Reservoir Calculations

The Churchill method for calculating sediment yield for reservoirs in series is illustrated by the following example. Consider three reservoirs in series as shown by figure 2. Sediment yield is first calculated for the headwater reservoir (reservoir 1 in fig. 2). The local yield for the area contributing to reservoir 1 is computed by:

$$LY = \left(\frac{AA}{LTE}\right)/LDA \tag{1}$$

where LY is the local yield,
AA is the average-annual accumulation,
LTE is the local trap efficiency (fig. 1b), and
LDA is the local contributing drainage area.

The outflow-sediment load is then:

$$OSL = \frac{AA}{LTE} - AA \tag{2}$$

where OSL is the outflow-sediment load. The outflow sediment load is assumed to be transported downstream to reservoir 2.

The sediment load flowing into reservoir 2 consists of sediment derived from the local contributing area and outflow sediment from reservoir 1. Thus the accumulated sediment in reservoir 2 must be adjusted for the sediment contributed from reservoir 1.

$$NLAR2 = AAR2 - [(OSLR1)(OTER2)] \tag{3}$$

where NLAR2 is the net local accumulation in reservoir 2,
AAR2 is the average-annual accumulation in reservoir 2,
OSLR1 is the outflow sediment load from reservoir 1, and
OTER2 is the outflow trap efficiency (fig. 1b) for reservoir 2.

Net local accumulation is then used to compute local yield just as average-annual accumultion was used for reservoir 1. The outflow sediment load from reservoir 2 consists of the sediment from reservoir 1 that was not trapped by reservoir 2 plus that part of the local sediment load that was not trapped by reservoir 2.

$$OSLR2 = (OSLR1)(1-OTER2) + (NLAR2)(1-LTER2) \tag{4}$$

where OSLR2 is the outflow sediment load from reservoir 2 and
LTER2 is the local trap efficiency for reservoir 2.

The computations described for reservoir 2 are repeated for all remaining downstream reservoirs. Thus the analysis "cascades" sediment from the headwater reservoir down through the reservoir system.

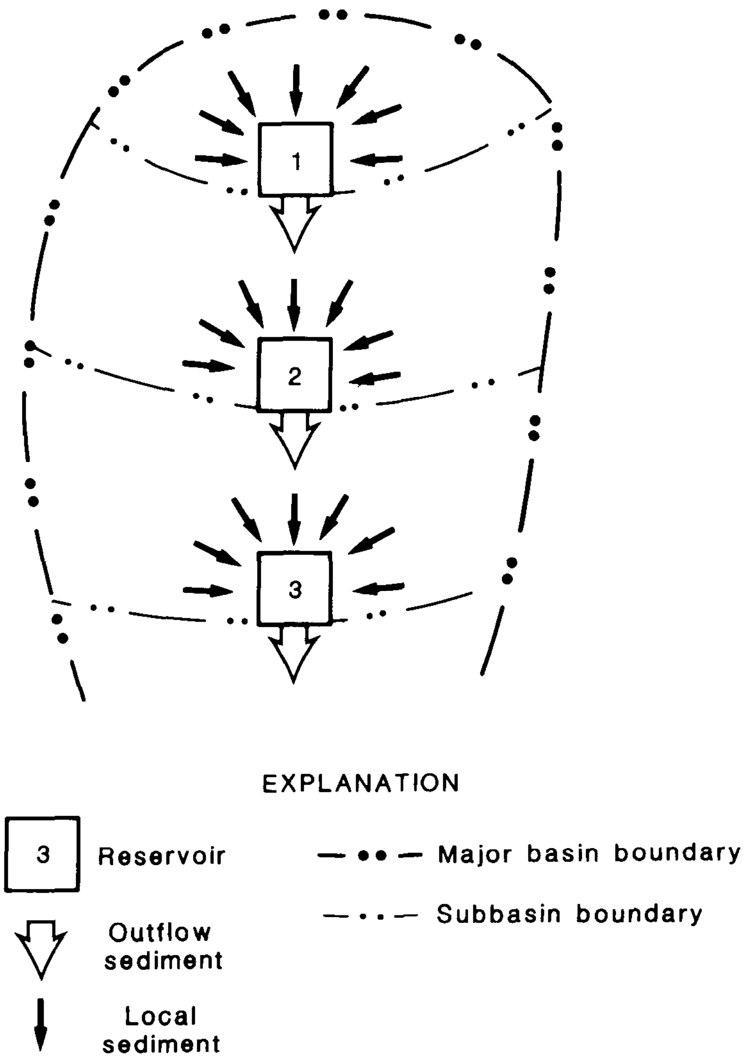


Figure 2.--Diagram of sediment contributions to reservoirs in series.

The Brune method is much more straight forward, because it does not account for sediment that has already passed through an upstream reservoir. The Brune method assumes that all accumulated sediment has come from the local contributing area. The local sediment yield is simply:

$$LSY = \frac{AA}{BTE} / LDA \tag{5}$$

where BTE is the Brune trap efficiency. Brune trap efficiencies used in this study were selected from the median curve in figure 1a. The envelope curves indicate the range of values plotted by Brune.

Because Churchill's curves were developed from TVA data, the Churchill estimates of sediment yield are considered more accurate except where noted in the discussion of yields. All trap efficiencies used in this study were rounded to the nearest 5 percent because of the uncertainties associated with estimating trap efficiencies.

Suspended-Sediment Data

Average annual suspended-sediment yield was calculated for each sediment sampling station by the flow-duration sediment-transport curve method (Miller, 1951). A flow-duration curve is simply a cumulative frequency distribution of the daily mean water discharges of a stream. For statistical reasons the flow-duration curve cannot be interpreted as a probability curve, however, a flow-duration curve does provide a description of the distribution of daily means that has occurred and can be considered as an estimate of the distribution during a future period several years long (Riggs, 1968 a and b). A sediment transport curve defines the average relation between the rate of sediment discharge and rate of water discharge for a particular sediment sampling site.

The suspended-sediment transport curve is constructed by first converting sampled (instantaneous) suspended-sediment concentrations in units of milligrams per liter to suspended-sediment discharge values in units of tons per day, using the following equation.

$$Q_s = Q_w C_s 0.0027 \tag{6}$$

where Q_s is instantaneous suspended-sediment discharge in tons per day,
Q_w is instantaneous water discharge in cubic feet per second, and
C_s is instantaneous suspended-sediment concentration in milligrams per liter.

The conversion of instantaneous values to values in units per day is necessary so that both the flow duration and sediment-transport data are expressed in units representing equal time periods.

The construction of the transport curve is completed by plotting the values of Q_s versus Q_w, usually on logarithmic graph paper, and then drawing a curve representing the mean sediment discharge for each water discharge. Transport curves can be constructed with either sediment concentration or sediment discharge as the independent variable, however, for graphical analysis the plot of Q_s versus Q_w has less scatter than the concentration plot, and mathematically the two relations are identical. Statistically, the good correlation in the Q_s versus Q_w relation is largely spurious because Q_w is a factor in both the independent and dependent variables. This spurious correlation does not preclude the use of Q_S versus Q_W as a graphic aid in constructing a transport curve and, mathematically it does not effect the results of sediment discharge calculations.

The details of the calculations used in this method are described in Vanoni (1975) and will not be covered here. However, it should be noted that average annual suspended-sediment yield, as used in this report, is equal to the average annual suspended-sediment discharge divided by the drainage area (in square miles) above the sampling station.

Most areal studies of measured suspended-sediment yield use a constant base period for developing flow-duration curves. Duration curves based on short-term records are adjusted, using a method described by Searcy (1959), to represent the longer base period. This adjustment minimizes low-flow and high-flow deficiencies caused by a given short-term record. Differences among sediment yields computed with a constant base period can then be better attributed to differences in climatic or drainage basin characteristics.

Sediment yields for the eight stations listed in table 1 as having good or excellent transport curves were computed using similar base periods. Six of these eight stations have periods of streamflow record ranging from 50 to 60 years. Flow duration curves for these six stations were not adjusted to a specific base period because the sample size is so large (greater than 18,000 daily mean flows) that adjustment to a common base period, for example a 55 year base, would be insignificant. The periods of record for the two remaining stations are both less than 20 years, and therefore both duration curves were adjusted. The adjustment for both stations proved to be insignificant. Flow-duration curves for the remaining stations with fair or poorly defined sediment-transport curves were not adjusted to a common base period. Inaccuracies in the definition of the transport relation for these sites far outweigh inaccuracies caused by unadjusted flow durations.

Sediment-yield values for stations with fair or poorly defined transport curves are listed as ranges in table 1. The computed yield for each station falls within the listed range. However, because the upper end of the transport curve at each of these stations had to be estimated, the true yield for any station could be different than the indicated range. Each listed range should be considered as an indication of the yield.

Relative Quality of Transport Relations

Porterfield (written commun., 1980) states that any extrapolation of a transport curve is based on many assumptions. The most important assumptions being that basin conditions affecting runoff, erosion, transport, and deposition during the sampled period are similar to those during the extrapolated period, and that a sufficient number of samples were obtained throughout the range of discharges to adequately define the curve.

Although the data collected in this study do not adequately define the complete transport curve, the TVA data for four stations are more than adequate for this purpose. Stations at which TVA data were collected during 1963-65 are considered to have well defined transport curves. Assuming that no significant basin changes have occurred since 1965, the transport relation defined by the TVA data represents the current relation.

Table 1.--Suspended-sediment yields from measured suspended-sediment data

[mi^2, square miles; (ton/mi^2)/yr, tons per square mile per year]

Station number	Station name	Drainage area, in mi^2	Yield, in (ton/mi^2)/yr	Data used to construct transport curve		Comments on the relative quality of the transport relation
				Agency and period of record	Number of samples	
07032200	Nonconnah Creek near Germantown.	68.2	500-1000	USGS 1979-1982	30	Fair - Relation linear but number of samples low.
07031650	Wolf River at Germantown	699	250-500	USGS 1979-1982	30	Fair - Relation linear but number of samples low.
07030240	Loosahatchie River near Arlington.	262	500-1000	USGS 1979-1982	30	Fair
07029500	Hatchie River at Bolivar	1480	150	USGS 1977-1982	64	Good - Relation is linear, high flow sampling 1977-1978.
07029100	North Fork Forked Deer River at Dyersburg.	939	500-1000	USGS 1979-1982	28	Fair
07026370	North Reelfoot Creek at Highway 22, near Clayton.	56.3	250-500	USGS 1979-1982	28	Fair
07026000	Obion River at Obion	1852[a] 1097[b]	720[d] 740[c]	USGS 1975-1981	74	Good- Curve analyzed and extended on rising and falling stage separations.
07025400	North Fork Obion River near Martin.	372	500-1000	USGS 1979-1981	25	Fair
07024500	South Fork Obion River near Greenfield.	383[a] 328[b]	250-500[c]	USGS 1979-1982	27	Fair
07024300	Beaver Creek at Huntingdon	55.5	510	USGS 1979-1982	27	Good - Data covers full range of flow, but number of samples is low.
03606500	Big Sandy River at Bruceton	205	250-500	USGS 1979-1982	25	Poor - Upper end of curve poorly defined.
03605555	Trace Creek above Denver	31.9	100-250	USGS 1979-1982	26	Fair - Relation defined by comparison with TVA Duck River data.
03604000	Buffalo River near Flat Woods.	447	100-250	USGS 1974-1982	48	Fair - Upper end defined by comparison with TVA data from Buffalo River near Lobelville.
03596000	Duck River below Manchester	107	100-250	USGS 1979-1982	27	Poor - Upper end defined by comparison with TVA data for Duck and Buffalo Rivers.
03588500	Shoal Creek at Iron City	348	<100	USGS 1979-1982	25	Poor - Upper end defined by comparison with TVA data from Duck and Buffalo Rivers.
03578000	Elk River near Pelham	65.6	250-500	USGS 1979-1981	15	Poor - Upper end defined by comparison with TVA data for Duck and Buffalo Rivers.
03571000	Sequatchie River near Whitwell.	402	130	USGS 1979-1981 TVA 1963-1965	>500	Excellent
03565500	Oostanaula Creek near Sanford.	57	250-500	USGS 1979-1981	30	Poor - Upper end defined by comparison with TVA data from several basins.
03540500	Emory River at Oakdale	764	110	USGS 1979-1981 TVA 1963-1965	>500	Excellent
03532000	Powell River near Arthur	685	360	USGS 1979-1982	25	Good - Upper end defined by comparison with TVA 1930's data from same station.
03518500	Tellico River at Tellico Plains.	118	<100	USGS 1979-1982	26	Poor - Upper end defined by comparison with TVA data from several basins.
03498500	Little River near Maryville	269	100-250	USGS 1979-1982	20	Poor - Upper end defined by comparison with Townsend and TVA 1930's data from Little River near Rockford.

Table 1.--Suspended-sediment yields from measured suspended-sediment data--Continued

Station number	Station name	Drainage area, in mi^2	Yield, in (ton/mi^2)/yr	Data used to construct transport curve		Comments on the relative quality of the transport relation
				Agency and period of record	Number of samples	
03497300	Little River above Townsend.	106	60	USGS 1965,1979-1982	30	Good - Upper end defined by 1965 samples, but number of samples low.
03487550	Reedy Creek at Orebank	36.3	100-250	USGS 1979-1982	28	Poor - Upper end defined by comparison with Powell River near Arthur TVA 1930's data.
03485500	Doe River near Elizabethton	137	<100	USGS 1979-1982	29	Poor - Upper end defined by comparison with Nolichucky at Embreeville TVA 1960's data.
03470000	Little Pigeon River at Sevierville.	353	100-250	USGS 1979-1982	24	Poor - Only one high flow sample; rest below 5 percent duration; upper end based on comparison with Little River near Maryville.
03465500	Nolichucky River at Embreeville.	805	420	USGS 1979-1982 TVA 1963-1965	>500	Excellent
03436100	Red River at Port Royal	935 [a] 749 [b]	250-500 [c]	USGS 1979-1982	26	Poor - Upper end defined by comparison with TVA data from several basins.
03436000	Sulphur Fork Red River near Adams.	186 [a] 120 [b]	500-1000 [c]	USGS 1979-1982	24	Poor - Upper end defined by comparison with TVA data from several basins.
03435770	Sulphur Fork Red River above Springfield.	65.6	500-1000	USGS 1979-1982	18	Poor - Upper end defined by one sample plus comparison with several other stations.
03434500	Harpeth River near Kingston Springs.	681	250-500	USGS 1979-1982	21	Poor - Upper end defined by comparison with TVA data from several stations.
03431700	Richland Creek at Charlotte Ave., at Nashville.	24.3	<100	USGS 1979-1982	29	Poor - Upper end defined by one sample plus comparison with several other stations.
03428500	West Fork Stones River near Smyrna.	237 [a] 72 [b]	250-500 [c]	USGS 1979-1982	21	Poor - Upper end defined by comparison with several other stations.
03428070	West Fork Stones at Manson Pike, at Murfreesboro.	165	100-250	USGS 1979-1981	17	Poor - Upper end defined by comparison with several other stations.
03427500	East Fork Stones River near Lascassas.	262	250-500	USGS 1979-1982	23	Poor - Upper end defined by comparison with several other stations.
03421000	Collins River near McMinnville.	640	100-250	USGS 1979-1981	18	Poor - Upper end defined by one sample and by comparison with other stations.
03418070	Roaring River above Gainesboro.	210	250-500	USGS 1979-1982	25	Poor - Upper end defined by one sample and by comparison with other stations.
03416000	Wolf River near Byrdstown	106	100-250	USGS 1979-1981	23	Poor - Upper end defined by comparison with TVA data for Emory at Oakdale.
03414500	East Fork Obey River near Jamestown.	202	100-250	USGS 1979-1981	19	Fair - Fair indication of where curve should be up to 0.2 percent duration.
03409500	Clear Fork near Robbins	272	<100	USGS 1976-1981	32	Fair - Fair indication of where curve should be up to 0.2 percent duration.
03408500	New River at New River	382	1100	USGS 1976-1981	Daily Record	N/A
03407876	Smoky Creek at Hembree	17.2	2300	USGS 1979-1981	Daily Record	N/A

a Total drainage area at station.
b Area between upstream and downstream stations.
c Yield for area between upstream and downstream stations.
d Yield for total drainage area.

Comparison of current data with the 1960's data provides support for this assumption by showing that the current data are in the same range and have similar central tendencies as the 1960's data.

Several comparisons of TVA 1960's curves with TVA 1930's curves show that the general shape of the transport curve at a given station is the same for both periods. Although this result was expected, the comparison was done to verify the use of 1930's data to provide general shape guidelines at stations lacking 1960's data. Stations for which transport curves were drawn based on comparison with 1930's curves are considered to have poor to good definition. Good definition indicates that recent U.S. Geological Survey data for that curve cover a wider range of water discharge than for a curve rated as poor.

Stations for which no TVA data exist are considered to have fair to poorly defined transport curves. Curves for these stations were developed by comparing the available data to a group of transport curves developed from TVA data. The current data are used to locate the lower and middle parts of the curve and the comparison curves provide guides to the probable shape of the upper end of the curve.

In West Tennessee, the general shape of the curves for all stations except Hatchie River at Bolivar, Tenn., is based on comparison with the relation for the Obion River at Obion, Tenn. Because of the similarities in land-use, geology, and drainage systems, this comparison is considered valid but the individual curves are rated fair to poor.

SUSPENDED-SEDIMENT TRANSPORT

Physical Characteristics

The characteristics of suspended-sediment transport curves reflect the physical characteristics of the suspended-sediment and bed material. The sediment load of a stream can be conveniently, although arbitrarily, divided into two transport categories; wash load and bed-material load. Wash load consists of particles of a finer size than most of the particles present in the bed material. Normally the wash load consists of particles finer than 0.062 millimeters (mm) (silt and clay size material) (USGS-OWDC, 1977). Bed-material load consists of particle sizes that are found in appreciable quantities on the streambed.

Because little energy is required to transport silt and clay size material, most streams flowing within their channels can transport as much wash load as is supplied to them. Consequently, the wash load of these streams is not a function of transport capacity but is instead a function of supply. For this reason, the quantity of fine sediment moved by these streams at a given time is nearly equal to that delivered to it by erosion processes within the drainage basin (Guy, 1964). This fine material is carried in suspension and, therefore, does not occur in appreciable quantities in the bed material. When streams exceed bankfull discharge, however, a part of their discharge begins to flow over flood plains that are usually vegetated. Because of the large hydraulic resistance of vegetated flood plains and resulting sluggish flow over these flood plains, the stream may no longer be able to transport all of the fine material supplied to it (Trimble, 1983). When this happens, the quantity of fine material being moved by the stream may no longer be indicative of erosion and delivery processes occurring within the basin.

As particle size increases, the energy required for transport also increases and the amount of this larger size sediment in transport becomes a function of the transport capacity of the stream and the supply of material available for transport. These larger particles move along the bed or in temporary suspension in the flow. Obviously, the transport capacity of a stream will vary from reach to reach for a given flow condition and it will vary for different flows at a given location. Thus, the particle size that can be used to distinguish between wash load and bed-material load is not fixed and will vary depending on local conditions. However, the arbitrary size of 0.062 mm is useful in distinguishing between the material that is easily transported by the full range of expected flows and the material that is at rest on the streambed during low flows and is mobilized only when specific transport conditions are met. It also serves as a general indicator of the contribution of bed material to the suspended load of a stream.

For the purpose of evaluating the contribution of bed material, the streams of Tennessee can be divided into channels with sand size bed material and channels with bed material ranging from gravel to bedrock. The sand bed channels are generally located west of the Tennessee River basin and the gravel to bedrock channels generally occur in middle and eastern Tennessee. The measured suspended-sediment data show that the contribution of material larger than 0.062 mm is usually less than 25 percent even in the sand bed channels of West Tennessee. This statewide preponderance of fine material indicates that the characteristics of the transport relations are determined primarily by the amount of wash load being transported by the stream.

Transport Characteristics

The shapes and slopes of suspended-sediment transport curves can be used to provide information about the processes responsible for stream sediment loads (Colby, 1956). Transport curves or segments of transport curves that appear linear on logarithmic paper can be described by the following log-linear equation:

$$\log_{10}(Q_s) = \log_{10}(a) + b \log_{10}(Q_w) \tag{7}$$

In algebraic form equation (7) is

$$Q_s = a\, Q_w^b \tag{8}$$

where Q_s is suspended-sediment discharge in tons per day,
a is a coefficient that can be considered as a indicator of relative erodibility,
Q_w is water discharge in cubic feet per second, and
b is an exponent representing the slope of the transport curve.

If the slope (b) is held constant and (a) is allowed to vary then each (a) will define a different line on the graph but all lines will be parallel. Lines with higher (a) values indicate that higher concentrations of suspended sediment are occurring for the same Q_w values. Most transport curves are not completely log-linear but they can be described by two or more line segments each with a different coefficient and exponent.

The slopes (b) of suspended-sediment transport curves also provide important information about sediment transport processes in a basin. Changes in slope along a single transport curve reflect changes in suspended-sediment concentration. When the slope of the transport curve equals one, suspended-sediment concentration is constant. Slopes greater than one indicate that suspended-sediment concentration is increasing and slopes less than one indicate decreasing concentrations. Accelerated erosion in a basin, whether caused by seasonal differences in rainfall and sediment supply or by land-disturbing activities, tends to shift transport curves to higher (a) values while having little effect on (b).

Suspended-sediment transport curves that are believed to be representative of the general shapes of curves for stations in Tennessee are shown in figure 3. The curves for Hatchie River at Bolivar and Obion River at Obion have much gentler slopes (lower b values) than the other curves. These two rivers, are in western Tennessee and flow in alluvial channels with sand beds and silt-clay banks. The remaining curves are for streams in middle and eastern Tennessee that flow on relatively stable coarse bed material or on bedrock.

Suspended-sediment concentrations in middle and eastern Tennessee streams are lower than in western Tennessee streams, for flows that are less than 1.0 $(ft^3/s)/mi^2$. As discharge increases above 1.0 $(ft^3/s)/mi^2$, transport curves for middle and eastern Tennessee streams become much steeper whereas those for western Tennessee either maintain a constant slope or flatten out. For some middle and eastern Tennessee streams, concentrations equal or exceed those for western Tennessee streams in the range of 1 to 10 $(ft^3/s)/mi^2$. Because of the predominately fine particle size of the suspended sediment, these relative changes in transport curve shape can be related directly to differences in erosion and delivery processes.

Initially higher concentrations in western Tennessee streams are most likely the result of direct contributions from channel beds and banks. These channel beds and banks are not armored with coarse material as are the beds and banks in most middle and eastern Tennessee streams. Although the main channels of western Tennessee have sand beds, the tributary channels tend to have silt-clay beds (personal observation). Therefore, a much larger supply of easily mobilized silts and clays is initially available for transport by the lower flows in western Tennessee streams.

As streamflow increases, sediment contributions from channel and upland erosion begin to enter the drainage system. In the authors' opinion, the steep rise in the Obion River curve reflects contributions from agricultural land that borders on the drainage network and contributions from channel bank erosion. The relative contribution of these two sources cannot be quantitatively assessed; however, because of the instability of the bed and banks of most channelized streams in western Tennessee (Robbins and Simon, 1982), it is reasonable to assume that the contribution from channel erosion is significant. It is known that channel clearing and straightening increases the mean velocity of flow, and this in turn substantially increases suspended sediment discharge and bedload (Colby, 1964). The almost constant slope of the Hatchie River curve indicates that the relation between suspended-sediment concentration and water discharge is poor. The lack of channelization on the Hatchie River and the absence of agricutural lands bordering directly on the Hatchie River channel are two major factors that may account for this poor relation. It should be noted that the Obion River is typical of most of the major channels and basins in western Tennessee (Robbins and Simon, 1982).

Transport curves for middle and eastern Tennessee streams are much steeper and generally do not exhibit a decrease in slope until very high discharges are reached. This curve shape indicates that the amount of suspended sediment entering the stream

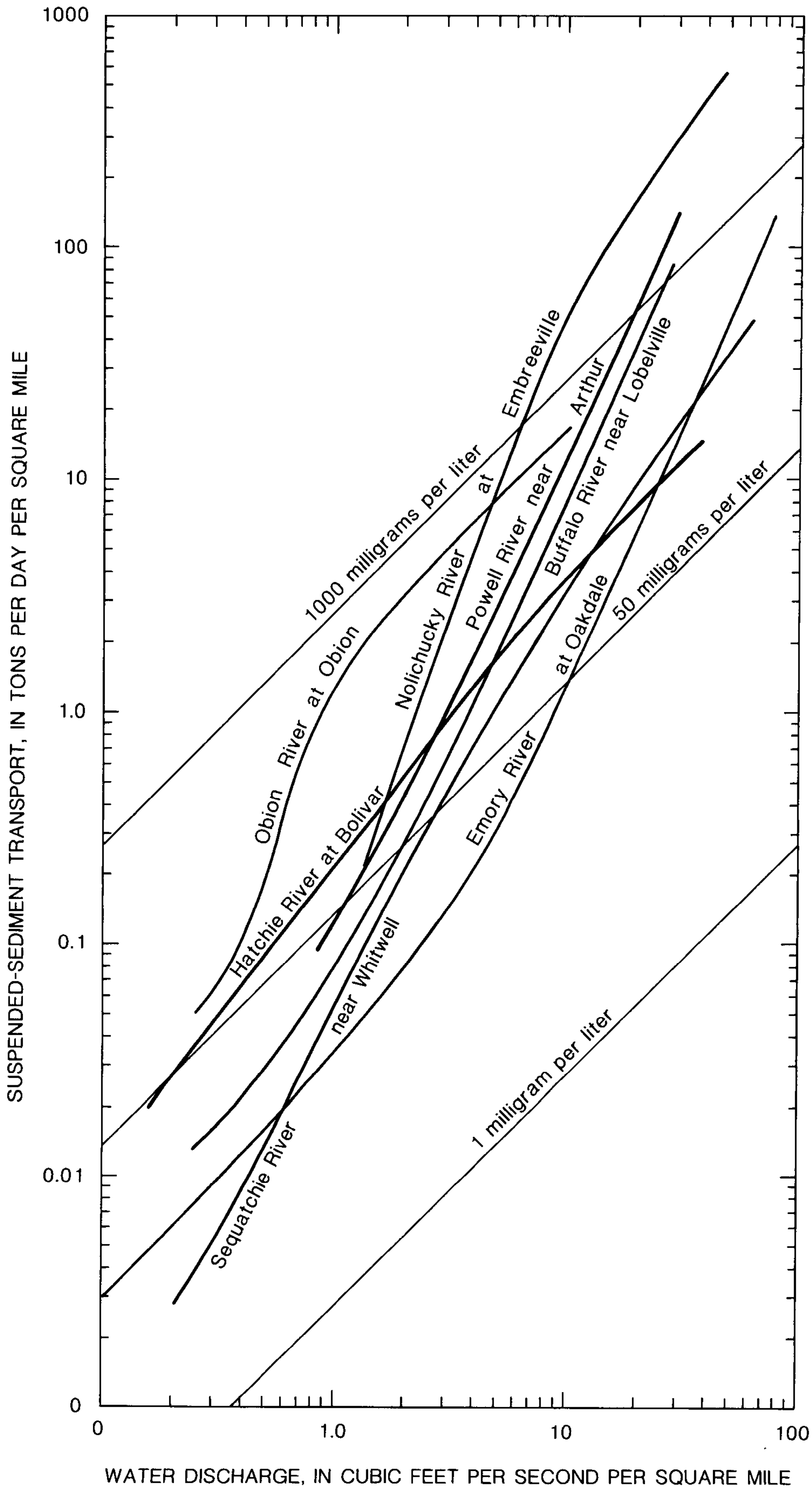


Figure 3.--Suspended-sediment transport curves for selected streams in Tennessee.

increases faster than the amount of water entering the stream until very high discharges are reached. The fact that concentrations in middle and eastern Tennessee can ultimately equal or exceed those in western Tennessee is a consequence of more efficient erosion and sediment delivery processes operating in these steeper basins.

SEDIMENT YIELD

Sediment Yield from Reservoir Calculations

Sediment yields calculated from Churchill curves range from 150 (tons/mi^2)/yr at Melton Hill to 2,600 (tons/mi^2)/yr at Ocoee No. 3 and for Brune curves the range is from 170 (tons/mi^2)/yr at Melton Hill to 4,100 (tons/mi^2)/yr at Ocoee No. 3 (table 2, fig. 4). The areally weighted mean yield is 630 (tons/mi^2)/yr for Churchill figures and 730 (tons/mi^2)/yr for Brune figures. The Brune values are all higher than the Churchill values but in general the two values are similar.

Increases of greater than 50 percent between Churchill and Brune yields occur at Fort Patrick Henry, Nolichucky, Ocoee No. 3, Ocoee No. 1, and Wilson Reservoirs. The remaining percentage differences range from 0 to 35 and average 9 percent. Both Fort Patrick Henry and Wilson Reservoirs have very low net contributing areas compared to their total drainage area. Fort Patrick Henry's net is only 3 percent of the total and Wilson's is only 4 percent. The calculation of sediment yield for these reservoirs is very sensitive to the amount of outflow sediment from an upstream reservoir. The amount of outflow sediment trapped by Fort Patrick Henry accounts for 43 percent of the total accumulation and in Wilson it accounts for 70 percent of the total. Reductions in the outflow trap efficiencies of these two reservoirs would result in substantially higher local sediment yields. The Brune yield probably represents a more realistic estimate for Fort Patrick Henry and a weighted average of Churchill values from Pickwick and Wheeler probably represents a more realistic estimate for Wilson [470 (tons/mi^2)/yr].

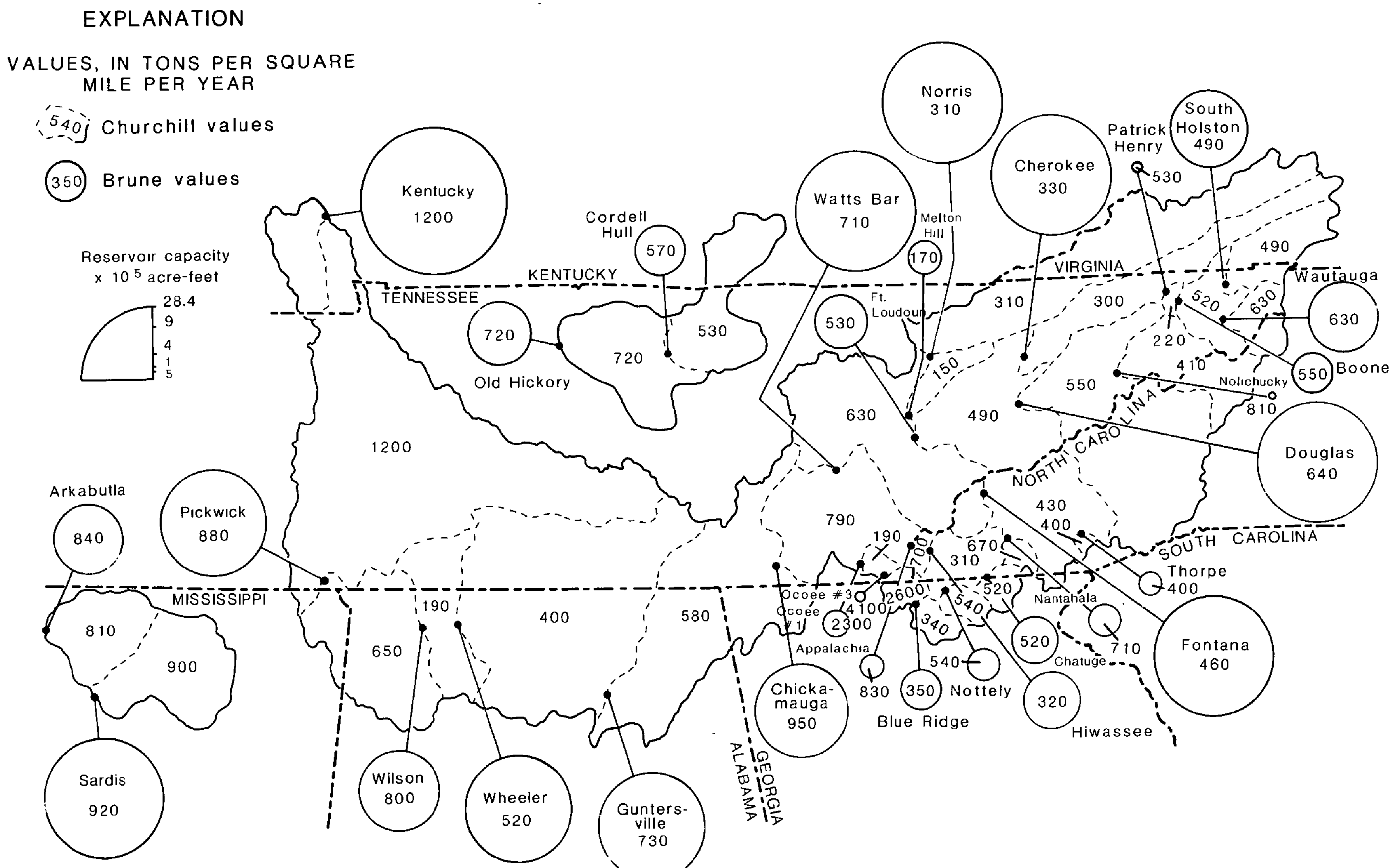
The difference in the Nolichucky yields is simply a function of the large difference in trap efficiencies that occurs at low TE values. The Brune yield is about two times the Churchill local yield, and the Brune TE is one-half the Churchill local TE. The average of the two yields 610 (tons/mi^2)/yr probably represents a more accurate estimate of the true yield for the Nolichucky drainage.

The Ocoee Reservoirs are downstream of the region known as the Copper Basin in the southeastern corner of Tennessee. Much of the forest in this basin was cut for use as mine timbers in the copper mines and also for use as charcoal in the refining furnaces. Sulfur dioxide fumes created by copper refining subsequently denuded a considerable area in the basin. The Copper Basin drains directly into Ocoee No. 3, thus accounting for the high sediment yields indicated by Ocoee No. 3. Ocoee No. 3 has relatively low TE's of 0.70 Churchill local and 0.45 Brune, which indicate that a substantial amount of sediment is passed on to Ocoee No. 1. Ocoee No. 1 has relatively high TE's of 80 Churchill outflow and 85 Brune. Calculation of Churchill local yield for Ocoee No. 1 is very sensitive to the high outflow TE combined with the large outflow load from Ocoee #3. The result is an apparent underestimation of the true yield. The Brune estimate is much too high because it does not account for sediment passed through an upstream reservoir. This case is similar to Wilson Reservoir where errors in the two methods offset the yield estimate in opposite directions. Based on surrounding yield information, the true yield for Ocoee No. 1 probably lies in the 300 to 700 (tons/mi^2)/yr range. The average of both values for Ocoee No. 3, 3,400 (tons/mi^2)/yr, can be used as a numerical estimate of the local yield.

Table 2.--Sediment Yields computed from reservoir data

[(ton/mi²)/yr, tons per square mile per year]

Reservoir	River	Period of record used	Churchill		Brune	Churchill local yield, in $(\text{ton/mi}^2)/\text{yr}$	Brune yield, in $(\text{ton/mi}^2)/\text{yr}$	Next reservoir downstream
			Local TE	Outflow TE	TE			
South Holston	South Holston	1950-1964	100	100	100	490	490	Boone
Wautauga	Wautauga	1948-1964	100	100	100	630	630	Boone
Boone	Holston	1952-1964	95	90	90	520	550	Fort Patrick Henry
Fort Patrick Henry	Holston	1953-1964	75	45	55	220	530	Cherokee
Cherokee	Holston	1954-1964	100	95	95	300	330	Fort Loudoun
Nolichucky	Nolichucky	1925-1970	60	15	30	410	810	Douglas
Douglas	French Broad	1943-1967	100	95	95	550	640	Fort Loudoun
Fort Loudoun	Tennessee	1946-1961	80	50	75	490	530	Watts Bar
Nantahala	Nantahala	1950-1969	100	100	95	670	710	Watts Bar
Thorpe	West Fork Tuckasegee.	1941-1969	100	100	100	400	400	Fontana
Fontana	Little Tennessee	1944-1967	100	100	95	430	460	Watts Bar
Norris	Clinch	1936-1970	100	95	100	310	310	Melton Hill
Melton Hill	Clinch	1963-1970	85	60	75	150	170	Watts Bar
Watts Bar	Tennessee	1946-1961	85	60	80	630	710	Chickamauga
Chatuge	Hiwassee	1942-1965	100	100	100	520	520	Hiwassee
Nottely	Nottely	1942-1965	100	100	100	540	540	Hiwassee
Hiwassee	Hiwassee	1947-1965	100	80	95	310	320	Appalachia
Appalachia	Hiwassee	1943-1965	90	70	75	700	830	Chickamauga
Blue Ridge	Toccoa	1944-1968	100	100	95	340	350	Ocoee #3
Ocoee #3	Ocoee	1942-1972	70	35	45	2600	4100	Ocoee #1
Ocoee #1	Ocoee	1954-1968	95	80	85	190	2300	Chickamauga
Chickamauga	Tennessee	1954-1961	75	35	70	790	950	Guntersville
Guntersville	Tennessee	1940-1961	80	45	75	580	730	Wheeler
Wheeler	Tennessee	1947-1961	75	40	70	400	520	Wilson
Wilson	Tennessee	1936-1961	75	40	60	190	800	Pickwick
Pickwick	Tennessee	1938-1961	75	40	70	650	880	Kentucky
Kentucky	Tennessee	1946-1961	75	45	80	1200	1200	
Cordell Hull	Cumberland	1973-1980	70	30	66	530	570	Old Hickory
Old Hickory	Cumberland	1954-1965	70	30	74	720	720	
Arkabutla	Coldwater	1939-1962	100	100	97	810	840	
Sardis	Little Tallahatchie.	1937-1960	100	100	98	900	920	



Base from Tennessee Valley Authority, 1976
Modified from N. Diaz and B. Atwell, Department of Geology, University of California at Los Angeles, 1983

Figure 4.--Sediment yields computed from reservoir data.

Another area of high sediment yield is the Kentucky Lake basin which is significantly higher than the surrounding watersheds. One possible explanation is that much of the sediment is coming from the west side of the Tennessee River where short, steep streams drain basins composed all or in part of the erodible coastal plain sediments of western Tennessee. Evidence for this comes from six small reservoirs just west of Kentucky Lake near Lexington, Tenn. The combined net drainage area of 40.75 mi^2 of these six basins has a weighted average sediment yield of 1,600 $(tons/mi^2)/yr$. These high values would be offset by low sediment yields from the western Highland Rim physiographic province on the east side of Kentucky Lake.

Both the Churchill and Brune yield figures for the Melton Hill drainage area appear to be anomalously low. A possible explanation for this anomaly is that Melton Hill has only 7 years of data and these years had runoff that was 17 percent lower than the long-term (63 year) average. Additional data from suspended-sediment sampling could help to explain yields from this basin as well as from the Kentucky Lake area.

Average Annual Sediment Concentrations from Reservoir Calculations

Sediment yield and outflow sediment data from the previous analysis were used to calculate sediment concentrations (table 3, fig. 5). Differences in sediment concentrations among the reservoirs may follow the differences in sediment yields because water runoff per unit area (unit runoff) is quite variable within the areas analyzed. The data presented in table 2 and figure 4 allowed analysis of the runoff for the local contributing area and for the reservoir water which would include not only local water but also water which had flowed through one or more reservoirs. Note that this analysis considers all particle sizes. Because only the finer sizes remain suspended, average concentrations determined from suspended-sediment data may vary considerably from the values obtained here.

Average annual local sediment concentration in milligrams per liter is computed by:

$$LSC = \frac{LSY}{LIW} 735.15 \tag{9}$$

where LSC is the average-annual local sediment concentration, in milligrams per liter;
LSY is the average-annual local sediment discharge, in tons;
LIW is the average-annual local inflow of water, in acre-feet; and
average annual inflow sediment concentration, in milligrams per liter, is computed by:

$$RSC = \frac{LSY + OYUR}{IW} 735.15 \tag{10}$$

where RSC is the average-annual inflow sediment concentration, in milligrams per liter;
OYUR is the average-annual outflow sediment discharge from upstream reservoirs, in tons; and
IW is the average annual inflow of water, in acre-feet.

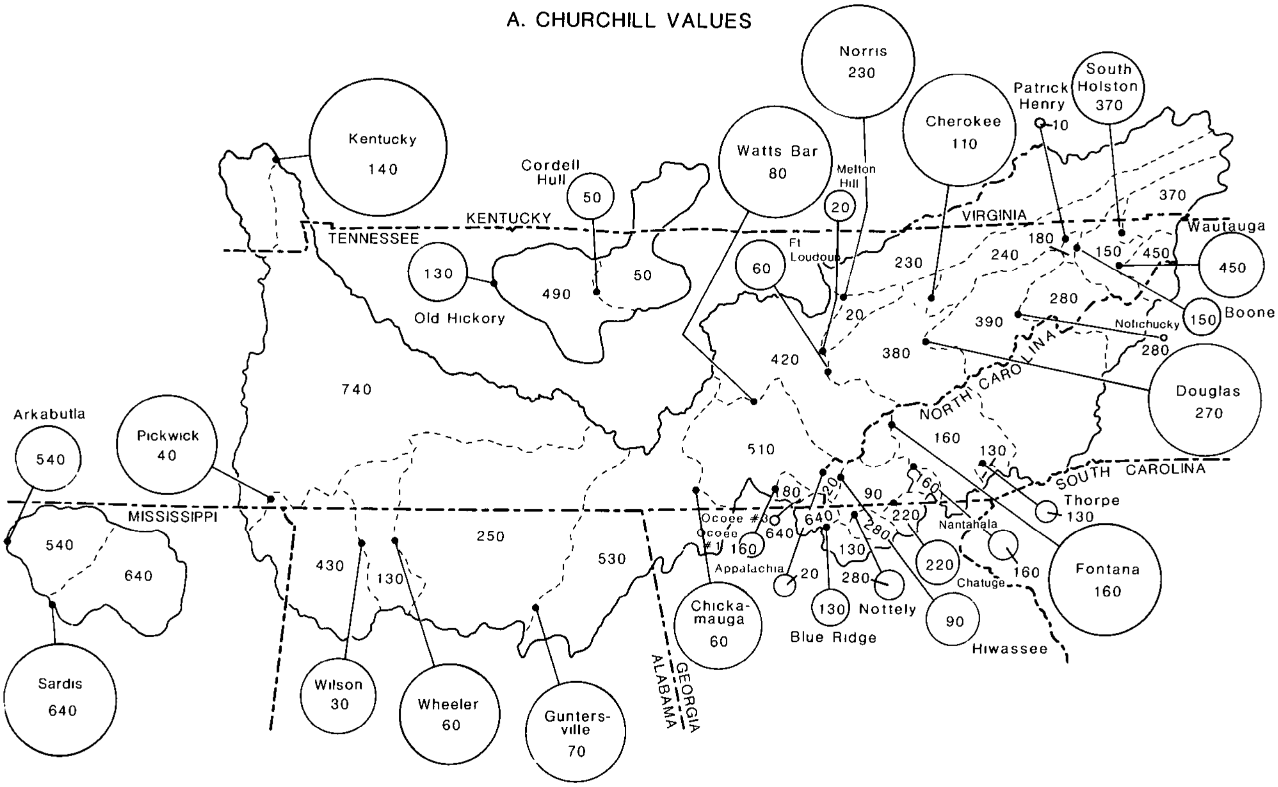
These computations were performed for both the Churchill and Brune methods. Average annual inflow of water was obtained from reservoir sedimentation data summary sheets (Dendy and Champion, 1969, 1973, 1978b; Spraberry, 1964).

Table 3.--Inflow and local sediment concentrations

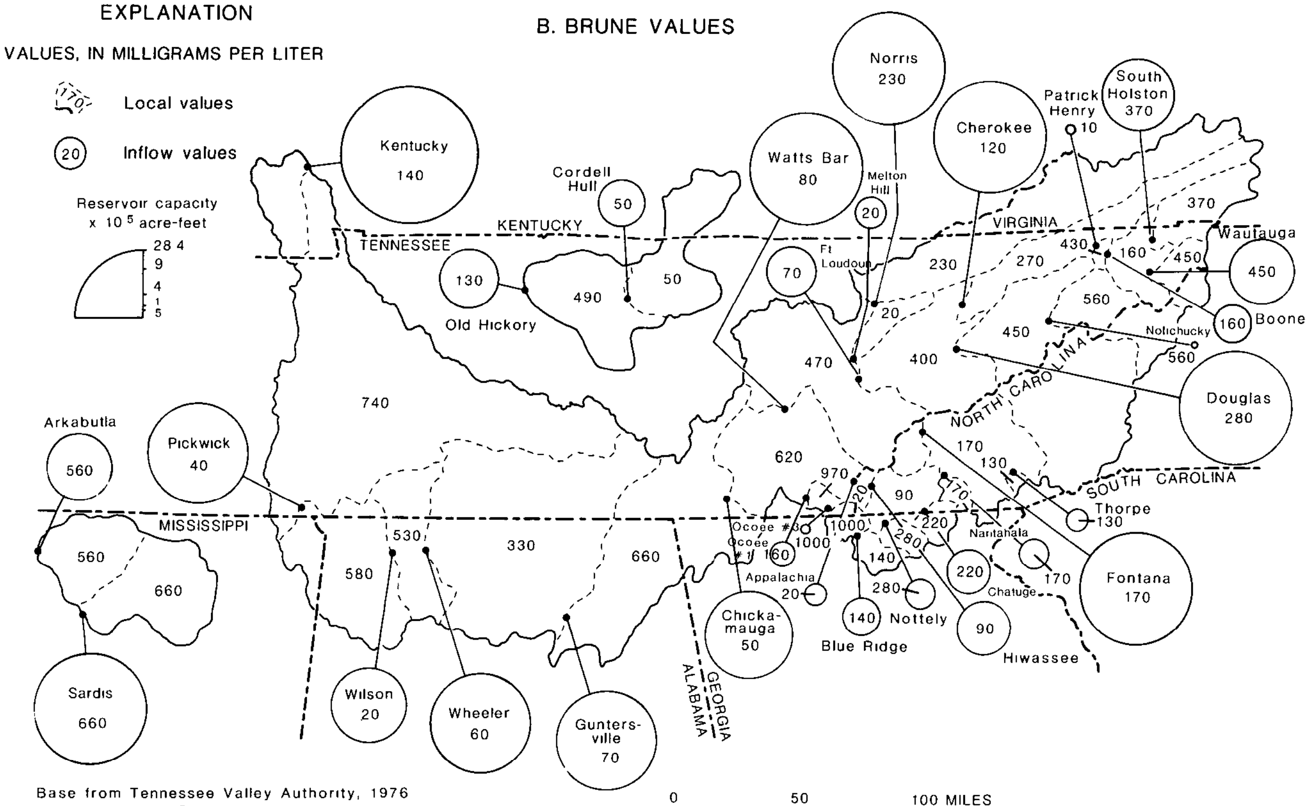
[mg/L, milligrams per liter]

Reservoir	Churchill inflow concentrations, in mg/L	Churchill local concentrations, in mg/L	Brune inflow concentrations, in mg/L	Brune local concentrations, in mg/L	Reservior	Churchill inflow concentrations, in mg/L	Churchill local concentrations, in mg/L	Brune inflow concentrations, in mg/L	Brune local concentrations, in mg/L
South Holston	370	370	370	370	Wilson	30	130	20	530
Wautauga	450	450	450	450	Pickwick	40	430	40	580
Boone	150	150	160	160	Kentucky	140	740	140	740
Fort Patrick Henry	10	180	10	430					
Cherokee	110	240	120	270					
Nolichucky	280	280	560	560	Cordell Hull	50	50	50	50
Douglas	270	390	280	450	Old Hickory	130	490	130	490
Fort Loudoun	60	380	70	400					
Nantahala	160	160	170	170	Arkabutla	540	540	560	560
Thorpe	130	130	130	130	Sardis	640	640	660	660
Fontana	160	160	170	170					
Norris	230	230	230	230					
Melton Hill	20	20	20	20					
Watts Bar	80	420	80	470					
Chatuge	220	220	220	220					
Nottely	280	280	280	280					
Hiwassee	90	90	90	90					
Applachia	20	20	20	20					
Blue Ridge	130	130	140	140					
Ocoee #3	640	640	1000	1000					
Ocoee #1	160	80	160	970					
Chickamauga	60	510	50	620					
Guntersville	70	530	70	660					
Wheeler	60	250	60	330					

A. CHURCHILL VALUES



B. BRUNE VALUES



Base from Tennessee Valley Authority, 1976
Modified from N Diaz and B Atwell, Department of Geology, University of California at Los Angeles, 1983

Figure 5.--Inflow and local sediment concentrations.

Local sediment concentrations reflect the concentrations in streams that drain directly into the reservoir. They range from 20 mg/L (Churchill and Brune) at Melton Hill and Appalachia to 740 mg/L (Churchill) at Kentucky and 1,000 mg/L (Brune) at Ocoee No. 3. Inflow sediment concentrations are indicative of concentrations in all surface-water infows to the reservoirs. They range from 10 mg/L (Churchill and Brune) at Fort Patrick Henry to 640 mg/L (Churchill) at Ocoee No. 3 and 1,000 mg/L (Brune) at Ocoee No. 3. Significant differences between Brune and Churchill values occur only at the same five reservoirs that had significant yield differences.

Comparisons between tables 2 and 3 are useful in distinguishing between yields caused by sediment concentration and those caused by runoff. Appalachia, for example, has relatively high local yield values for both the Churchill and Brune analysis, 700 (tons/mi^2)/yr and 830 (tons/mi^2)/yr, respectively. The local concentration value for Appalachia is only 20 mg/L for both the Brune and Churchill analysis. Obviously the relatively high yield must be the result of high inflows and does not indicate a sediment problem in the Appalachia local drainage.

Time Trends of Sediment Yields Using Reservoir Calculations

Because reservoir sediment has been measured periodically, it is possible to obtain an approximation of accumulation rates for different periods of time. Such accumulation rates are useful only when sediment transport from upstream has not been changed during the period of measurement by closure of an upstream reservoir. Criteria for inclusion of a reservoir in the time-trend analysis were that (1) the status of the two nearest upstream reservoirs had not changed during the periods of measurement and (2) at least three time periods could be included for each reservoir. These criteria limited the analysis to 15 reservoirs, all in the TVA system. The accumulation rate for each period, usually 5-7 years, was adjusted to estimate sediment yield by use of the Brune TE existing at the time. Trend lines were calculated for the series of surveys. There appears to be no overall trend: seven reservoirs show a decrease and eight show an increase. A spatial array of these values shows no geographical clustering of similar trends.

Suspended-Sediment Yield in Streams

Western Tennessee

Suspended-sediment data indicate that sediment yields in western Tennessee range from 250 to 1,000 (tons/mi^2)/yr. A notable exception, however, is the Hatchie River at Bolivar where suspended-sediment yield is 150 (tons/mi^2)/yr (table 1). The Hatchie River is a National Scenic River, and as such its main channel and associated flood plain have been protected from the dredging, straightening, and draining activities that characterize most West Tennessee rivers. These land-use restrictions on the Hatchie River main stem and flood plain significantly retard the delivery of eroded soil to the Hatchie and thus result in a low measured sediment yield.

Because most major channels in west Tennessee have sand beds, it is worthwhile to examine the contribution of unmeasured sediment discharge to the annual sediment yield. Unmeasured load is defined as the difference between the total sediment load and the measured suspended-sediment load of a stream (USGS-OWDC, 1977). Because the nozzle of standard suspended-sediment samplers descends to within approximately 3 inches of the bed, a part of the total sediment discharge remains unsampled. This unsampled or unmeasured load can account for a significant part of the total load, particularly in sand-bed streams. Several methods of varying complexity are available for estimating unmeasured load (Vanoni, 1975; and Chang and others, 1965). The method used in this analysis was developed by Colby (1957). Colby's method was developed for sand bed streams and makes use of data for a particular site. Unmeasured load was calculated for the Obion River at Obion with the following results:

1. Unmeasured load as a percentage of measured load = 6.5 percent.
2. Unmeasured load as a percentage of total load = 6.1 percent.

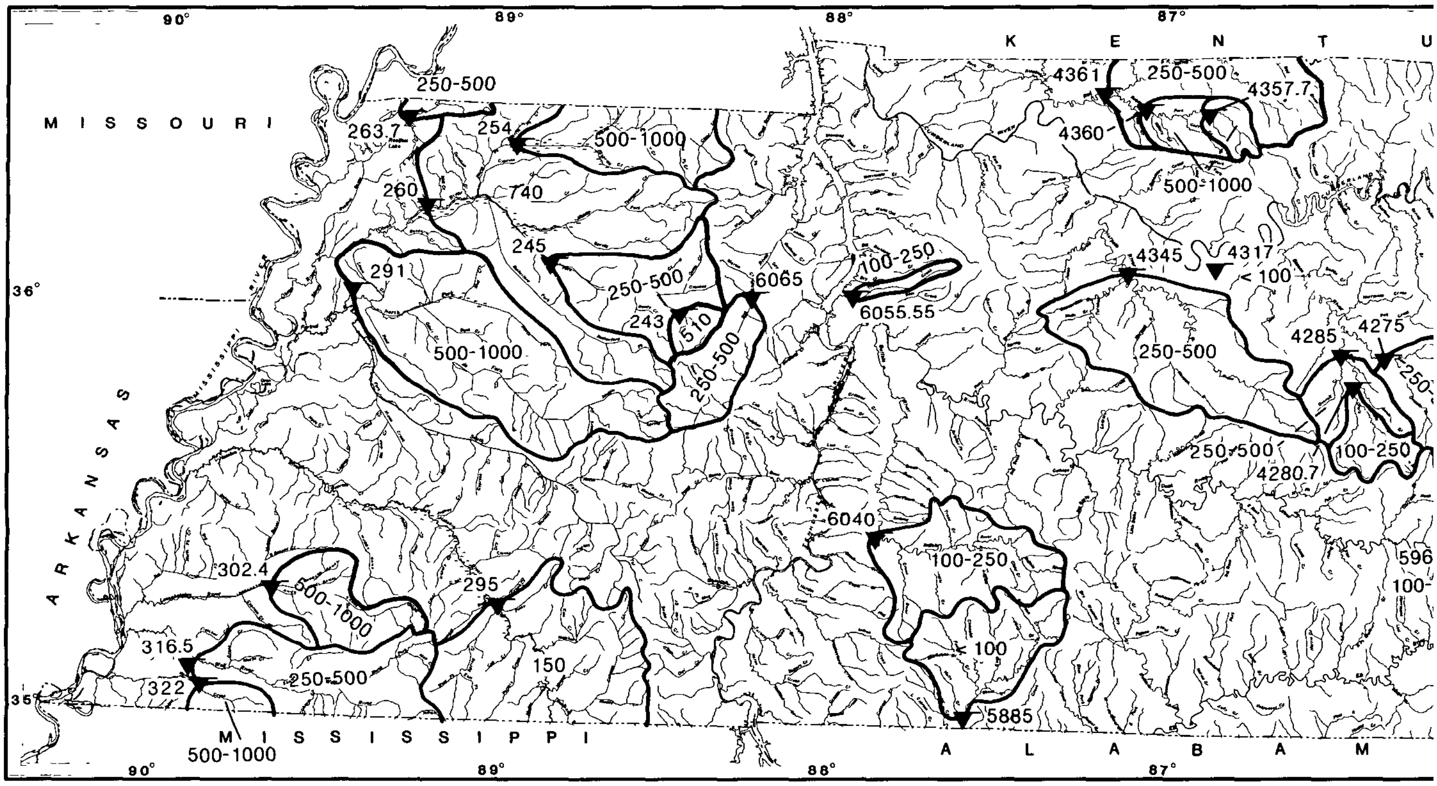
The small contribution of unmeasured load again reflects the preponderance of wash load in western Tennessee streams. Because of the small contribution of unmeasured load, similar calculations were not carried out for the remaining western Tennessee streams. The assumption is that the other channels in western Tennessee are similar to the Obion River and, consequently, there are no significant differences in the unmeasured load contribution.

Middle and Eastern Tennessee

For the basins in middle and eastern Tennessee where the sediment transport relation is considered good or excellent, yields range from 60 (tons/mi^2)/yr for Little River above Townsend (no. 4973 on fig. 6) to 2,300 (tons/mi^2)/yr for Smoky Creek at Hembree (no. 4078.76 on fig. 6). These two basins are representative of quite different land uses. The Little River above Townsend basin lies almost entirely with the Smoky Mountains National Park. Land disturbance in the basin is limited to a few residences and a small, mostly paved road network. In contrast, the Smoky Creek basin is heavily strip mined with an extensive unpaved road network and some flood plain agricultural activity.

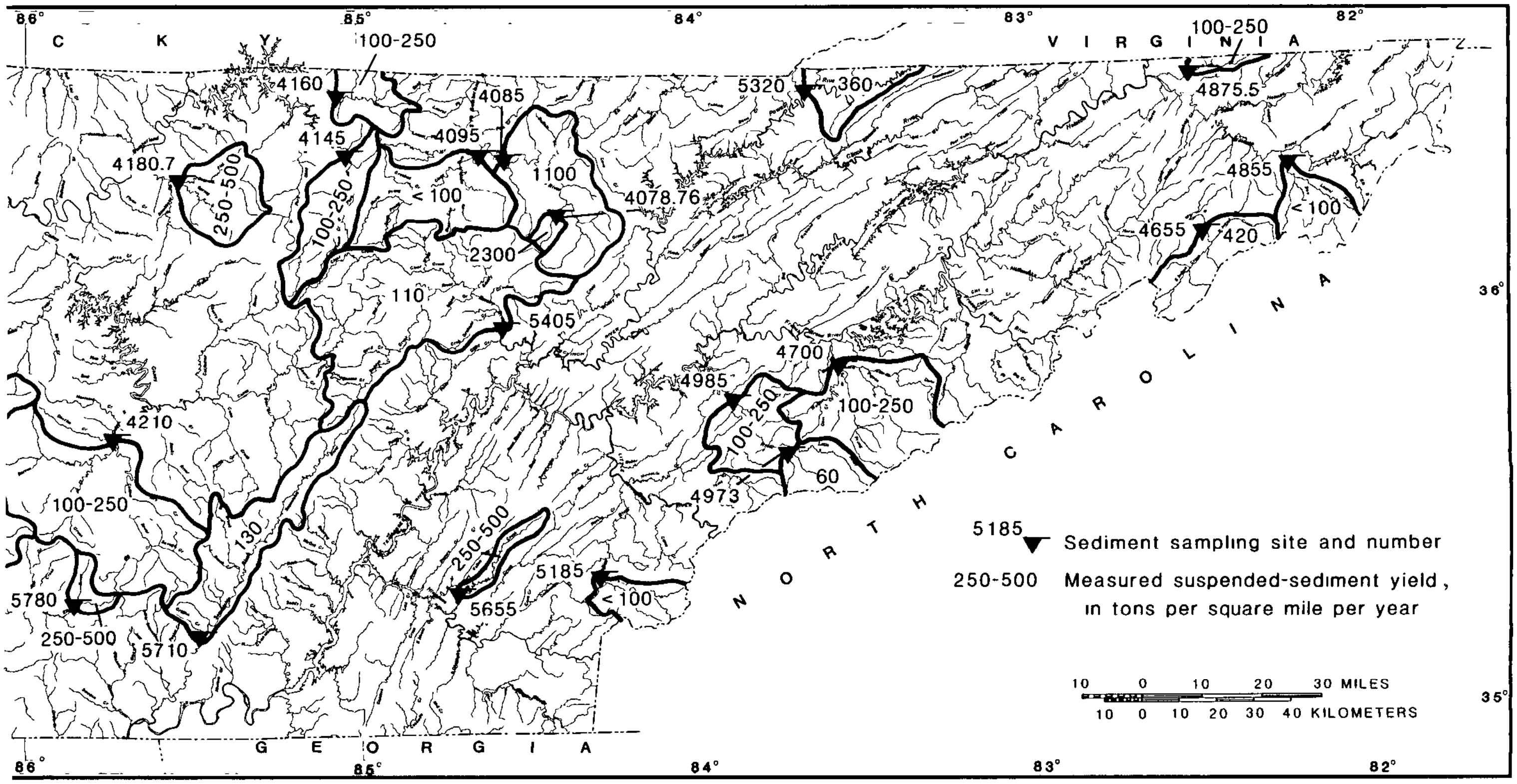
Anomalously high sediment yields in middle and eastern Tennessee are related to specific localized land disturbing activities. The Ducktown copper-mining area was mentioned previously and the high sediment yield from the heavily strip mined New River and Smoky Creek basins are shown in figure 6 and table 1. The limited data collected in this study indicate that the Red River basin may also have relatively high sediment yields. Sediment yield calculations at the three sampling stations in this basin resulted in high average annual yields even when the upper end of the transport relation was estimated conservatively. The reason for unusually high sediment yields in the Red River is not known, but intense agricultural activity is the most probable cause. This pattern of specific areas of land disturbance and high sediment yields in middle and eastern Tennessee is quite different from the more widespread land disturbing activities of western Tennessee.

Additional measured suspended-sediment yield data from southern Kentucky and the unpublished results of the 1963-65 TVA study provide support for the results presented in figure 6 and table 1. Flint (1983) reports sediment yields for southern Kentucky that range from 500 to 1,000 (tons/mi^2)/yr in southwestern Kentucky, to 250 to 500 (tons/mi^2)/yr in southern middle and southeastern Kentucky. Flint also shows yields greater than 2,000 (tons/mi^2)/yr for heavily mined basins in southeastern Kentucky. The general climate, physiography, and geology of southern Kentucky are essentially the same as in Tennessee. Unpublished results of the TVA 1963-65 study (TVA, written



BASE FROM U S GEOLOGICAL SURVEY
STATE BASE MAP, 1957, REVISED 1973

Figure 6.--Location of sediment sampl



sites and measured suspended-sediment yield.

commun., 1981) show that of the 10 basins sampled, only 1 had a yield greater than 500 (tons/mi^2)/yr, 5 basins had yields ranging from 250 to 500 (tons/mi^2)/yr, and 4 had yields under 250 (tons/mi^2)/yr.

Summary of Sediment Yield Information

A summary of reservoir sediment yield data for middle and eastern Tennessee streams is shown in table 4. For yields of 0 to 1,000 (tons/mi^2)/yr increments of 100 (tons/mi^2)/yr were chosen to present a more detailed picture than figure 4. The yield statistics for the Tennessee River basin are shown separately from the combined Tennessee River and Cumberland River summary because much more data are available for the Tennessee basin. The total Tennessee basin area represented in table 4 is 38,860 mi^2 which is 97 percent of the 40,200 mi^2 drainage for Kentucky Lake. The 3 percent difference is most likely due to measurement and rounding errors.

The Churchill data summaries presented in table 4a show that approximately 83 percent of the middle and eastern Tennessee area has sediment yields less than 800 (tons/mi^2)/yr. The areally weighted mean yield is 630 (tons/mi^2)/yr for both the Tennessee basin data and the combined Tennessee and Cumberland data. The modal class is 400 to 499 (tons/mi^2)/yr for both the Tennessee basin data and the combined data. The Brune data summaries presented in table 4b show that approximately 83 percent of the middle and eastern Tennessee area has sediment yields less than 1,000 (tons/mi^2)/yr. The areally weighted mean yield is 740 (tons/mi^2)/yr for the Tennessee basin and 730 (tons/mi^2)/yr for the combined Tennessee and Cumberland data. The modal class is 500 to 599 for the Tennessee basin and 700 to 799 for the combined area.

The Brune data reflect not only the general increase in Brune numbers over Churchill numbers but also the influence of the high yields for Ocoee No. 3, Ocoee No. 1, and Kentucky. Therefore, the Brune summary presented in table 4b is biased towards high values. The Churchill data, however, offset the high yield of Ocoee No. 1, and Kentucky with low yields for Fort Patrick Henry, Ocoee No. 1, and Wilson. Therefore the Churchill data summary given in table 4a is probably a more realistic representative of sediment yields in Tennessee.

A similar analysis is shown in table 4 for the suspended-sediment data; however, larger class intervals are used because many of the measured yields are derived from fair or poorly defined transport curves. In order to calculate percentages, interval midpoints were used for stations where a range of yield is listed in table 1. The suspended-sediment data for all middle and eastern Tennessee stations in table 1 have a weighted mean yield of 300 (tons/mi^2)/yr and a modal class of 250 to 500 (tons/mi^2)/yr. If the Churchill reservoir data are rearranged using the suspended-sediment class intervals, then the reservoir modal class is 500 to 1,000 (tons/mi^2)/yr. Therefore both the mean yield and modal class of the reservoir data are approximately twice the mean yield and modal class of the suspended-sediment data. The data and analyses presented in this study are not sufficiently detailed to determine the reasons for this discrepancy, however, it is possible to present some of the more probable reasons.

First of all, extreme caution should be exercised when comparing the two data bases. The reservoir data are longer term, more comprehensive areally, and more comprehensive in terms of inclusion of all sediment-transporting events. Also, the

Table 4a.--Summary of sediment yield data for middle and eastern Tennessee streams using the Churchill Method

Reservoir data								Measured data					
Yield class, in tons/(mi^2)/yr	Contributing area Tennessee basin, in mi^2	Contributing area Cumberland basin, in mi^2	Total contributing area, in mi^2	Percent of area Tennessee basin	Percent of combined area	Cumulative percent Tennessee basin	Cumulative percent combined area	Yield class, in tons/(mi^2)/yr	Contributing area, in mi^2	Percent of total area	Reservoir percent combined area	Measured cumulative percent	Reservoir cumulative percent
100-199	1653	---	1653	4.2	3.8	4.2	3.8	0-100	1005	11.3	---	11.3	---
200-299	62	---	62	0.2	0.1	4.4	3.9	100-250	3523	39.6	4.0	50.9	4.0
300-399	5066	---	5066	13.0	11.8	17.4	15.7	250-500	3792	42.6	34.9	93.5	38.9
400-499	9922	---	9922	25.5	23.1	42.9	38.8	500-1000	186	2.1	43.9	95.6	82.8
500-599	7442	1350	8792	19.2	20.5	62.1	59.3	1000-2000	382	4.3	16.6	99.9	99.4
600-699	5468	---	5468	14.1	12.7	76.2	72.0	2000-3000	17	0.2	0.6	100.1	100.0
700-799	1853	2741	4594	4.8	10.7	81.0	82.7						
800-899	0	---	0	0	0	81.0	82.7						
900-999	0	---	0	0	0	81.0	82.7						
1000-1999	7131	---	7131	18.4	16.6	99.4	99.3						
2000-2999	263	---	263	0.7	0.6	100.1	99.9						

Table 4b.--Summary of sediment yield data for middle and eastern Tennessee streams using the Brune method

Reservoir data								Measured data					
Yield class, in tons/(mi ^{2})/yr	Contri-buting area Tennessee basin, in mi ^{2}	Contri-buting area Cumberland basin, in mi ^{2}	Total contri-buting area, in mi ^{2}	Percent of area Tennessee basin	Percent of combined area	Cumulative percent Tennessee basin	Cumulative percent combined area	Yield class, in tons/(mi ^{2})/yr	Contri-buting area, in mi ^{2}	Percent of total area	Reservoir percent combined area	Measured cumulative percent	Reservoir cumulative percent
100-199	422	---	422	1.1	1.0	1.1	1.0	0-100	1005	11.3	0	11.3	0
200-299	---	---	---	0	0	1.1	1.0	100-250	3523	39.6	1.0	50.9	1.0
300-399	5066	---	5066	13.0	11.8	14.1	12.8	250-500	3792	42.6	16.8	93.5	17.8
400-499	2151	---	2151	5.5	5.0	19.6	17.8	500-1000	186	2.1	64.8	95.6	82.6
500-599	7699	1350	9049	19.8	21.1	39.4	38.9	1000-2000	382	4.3	16.6	99.9	99.2
600-699	3312	---	3312	8.5	7.7	47.9	46.6	2000-3000	17	0.2	0.2	100.1	99.4
700-799	6553	2741	9294	16.9	21.6	64.8	68.2	>3000	---	---	0.6	---	100.0
800-899	4362	---	4362	11.2	10.2	76.0	78.4						
900-999	1805	---	1805	4.6	4.2	80.6	82.6						
1000-1999	7131	---	7131	18.4	16.6	99.0	99.2						
2000-2999	96	---	96	0.2	0.2	99.2	99.4						
>3000	263	---	263	0.7	0.6	99.9	100.0						

contribution of unmeasured load in middle and eastern Tennessee has not been assessed. This contribution is believed to be small, but it cannot be determined easily for channels with coarse and variable bed material. In addition, the abundance of estimated yields in table 1 can cause significant error in statistical results. Therefore, the middle and eastern Tennessee data presented in this report are best considered as follows:

- The long-term total sediment yields for middle and eastern Tennessee are best represented by the results of the reservoir data analyses.
- Current suspended-sediment yields are available for individual basins with good or excellent transport relations and the two basins with daily sampling records.
- Comparisons between individual basins and reservoirs are discouraged unless the basin accounts for nearly all of the area contributing to the reservoir. This situation does not occur in this study.

Reservoir and suspended-sediment yields show better agreement for the western Tennessee data. The weighted mean yield for the two reservoirs in northern Mississippi is 860 (tons/mi^2)/yr Churchill and 890 (tons/mi^2)/yr Brune. With the exception of the Hatchie River basin, the weighted mean yield for the suspended-sediment data is 639 (tons/mi^2)/yr. The suspended-sediment yield for the 1,852 mi^2 basin above the Obion River at Obion station is 722 (tons/mi^2)/yr (table 1). This basin alone accounts for almost half of the measured area not included in the Hatchie River basin. This similarity between measured and reservoir yields can be attributed primarily to better sampling and smaller estimation errors.

Western Tennessee streams rise and fall much more slowly than middle and eastern Tennessee streams. Therefore, even with a miscellaneous sampling scheme, there is a much better chance of sampling the critical rising-stage flows. Also, the lower slope of the transport curves for these streams tends to reduce errors involved with extending the relation beyond available data.

The relatively small difference in mean sediment yield between western Tennessee basins and middle and eastern Tennessee basins is quite surprising when considering the highly publicized erosion problem in western Tennessee. As an example, gross erosion from all sources in the Obion-Forked Deer River basin is estimated to be 15,900 (tons/mi^2)/yr (USDA, 1977). Agricultural sources account for 71 percent or 11,300 (tons/mi^2)/yr (USDA, 1977). Measured suspended-sediment yield at Obion River at Obion, which accounts for 79 percent of the Obion basin, is 720 (tons/mi^2)/yr. The resulting ratio of suspended-sediment yield to gross erosion is 4.5 percent. This ratio is often called the delivery ratio and agrees well with published ratios for basins of this size (Vanoni, 1975). Thus the results of the present study indicate that only a small percent of the annual gross erosion is being discharged from the major basins of western Tennessee. In view of the considerable public interest in erosion processes in western Tennessee, it would be of great benefit to know more about the relation between gross erosion and real soil loss.

CONCLUSIONS AND RECOMMENDATIONS FOR FURTHER STUDIES

Results of this study show that suspended sediment transported by Tennessee streams consists mostly of silt and clay-size material. Measured suspended sand concentrations rarely exceed 25 percent of the sampled concentrations even in the sand bed channels of western Tennessee. Calculations of unmeasured load for these sand bed channels indicate that unmeasured load accounts for less than 10 percent of the total sediment load. Unmeasured load has not been determined for middle and eastern Tennessee streams because the bed material is generally coarse and quite variable. However, unmeasured load in these streams is believed to be only a small percentage of total load.

Suspended-sediment transport curves show that when flow is less than about 1 $(ft^3/s)/mi^2$, western Tennessee streams have higher concentrations; but when flow exceeds about 10 $(ft^3/s)/mi^2$, concentrations in middle and eastern streams can equal or exceed those in western streams. The more efficient delivery processes operating in middle and eastern Tennessee basins are responsbile for the rapid increases in suspended-sediment concentrations with increasing flow.

Sediment yields for middle and eastern Tennessee basins generally are less than 800 tons per square mile per year, however, heavily strip-mined basins can have yields from 1,000 to 3,000 $(tons/mi^2)/yr$. Yields for the heavily agricultural and channelized basins of western Tennessee generally range from 700 to 1,000 $(tons/mi^2)/yr$. Yields for the Hatchie River in western Tennessee are less than 200 tons per square mile per year reflecting the lack of flood plain agriculture and channelization.

This report has presented a statewide picture of the nature and quantity of sediment being transported by Tennessee streams. The following list of recommended studies is oriented toward providing more detailed information on specific problems or drainage basins.

1. A more detailed investigation of erosion processes in western Tennessee with the specific objective of estimating the amount of gross erosion that is actually lost from agricultural land.
2. More intensive sediment transport studies in western Tennessee to determine sediment yields for various basin sizes and land uses. This information would be particularly helpful in assessing the impact of proposed lignite mining.
3. Investigation of the reasons for the apparent high sediment yields in the Red River basin of middle Tennessee.
4. A more comprehensive analysis of the available reservoir data and the TVA suspended-sediment data. Objectives of this study would include more detailed specific basin analyses, characterization of suspended-sediment yields in the Tennessee Valley prior to impoundment, and time trend analyses to determine how sediment yields have changed in response to better land management.
5. An investigation of the factors contributing to discrepancies in the sediment yields determined by reservoir and transport curve methods.
6. A study of fluvial processes in the Hatchie River and how they are effected by tributary straightening and land-use practices in tributary basins.

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