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Effective Discharge Calculation

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PURPOSE: The purpose of this Technical Note is to describe the methodology known as the effective discharge approach for estimating channel-forming discharge in stable alluvial streams.

INTRODUCTION: While channel-forming discharge presented by ERDC/CHL HETN-II-5 can be estimated by two other methodologies (the bankfull discharge and the specified recurrence interval discharge, only the effective discharge approach is discussed here. The effective discharge transports the largest fraction of the bed-material load and, hence, can be a good estimator for channel-forming discharge. However, the effective discharge should not be assumed to be the channel-forming discharge a priori without confirmation using field indicators of geomorphic significance. This procedure for effective discharge calculations has been developed for a range of river types. It is a systematic method designed to have general applicability. The effective discharge procedure requires both hydrological and sediment data.

COMPUTATIONAL PROCEDURE: The procedure to determine the effective discharge is executed in three major steps which are as follows: (a) the flow-frequency distribution is determined from available flow-duration data, (b) sediment data are used to construct a bed-material-load rating curve, and (c) the flow-frequency distribution and bed-material-load rating curve are combined to produce a bed-material-load histogram which displays sediment load as a function of discharge for the period of record. The histogram peak indicates the effective discharge (Figure 1).

FLOW-FREQUENCY DISTRIBUTION: The flow-frequency distribution is developed from a flow-duration curve. The flow-duration curve can be developed from gauge data from or near the project reach or from physiographically similar watersheds.

When Gauge Data Are Available: The record from a single gauging station can be used to develop the flow-duration curve if the gauge is in close proximity to the project reach and the discharge record at the gauge is representative of the flow regime in the project reach. It is important that watershed conditions have remained unchanged during the selected historical flow period. The period of record must be sufficiently long to include a wide range of morphologically-significant flows, but not so long that changes in the climate, land use or runoff characteristics of the watershed produce significant changes with time in the data. A reasonable minimum period of record for an effective discharge calculation is about 10 years, with 20 years of record providing more certainty that the range of morphologically significant flows is fully represented in the data.

Mean daily discharges are conventionally used to construct the flow-duration curve. However, this can in some cases, introduce error into the calculations because mean daily values can under-represent the occurrence of short-duration, high magnitude flow events that occur within the

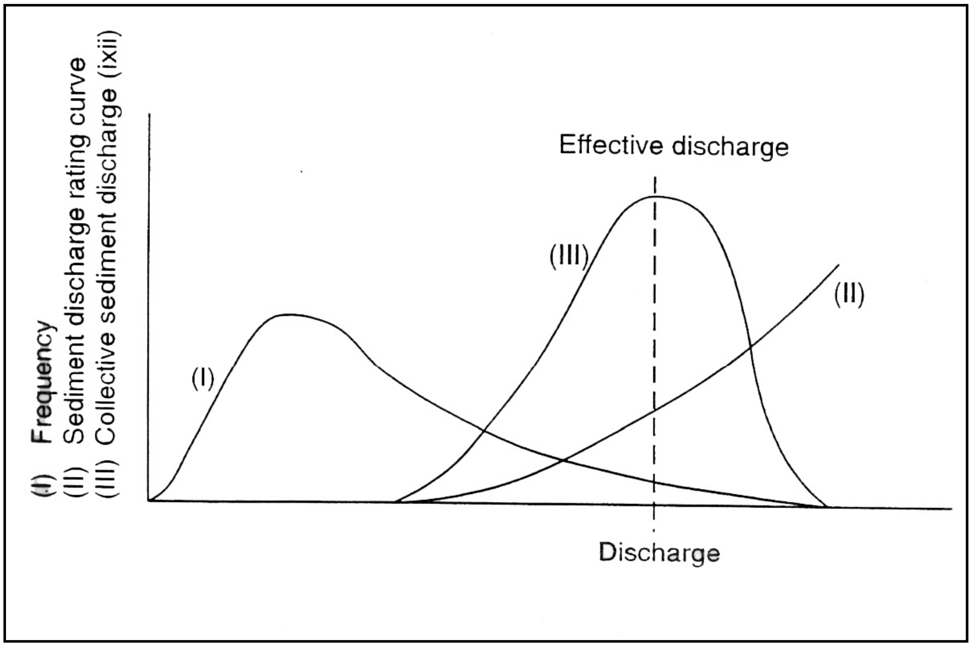

Figure 1. Derivation of total sediment load-discharge histogram (iii) from flow frequency (i) and sediment load rating curves (ii)

averaging period. On large rivers such as the Mississippi River, the use of the mean daily values is acceptable because the difference between the mean and peak daily discharges is negligible. On smaller streams, flood events may last only a few hours, so that the peak discharge is much greater than the corresponding mean daily discharge. The time base for discharges used to develop the flow-duration curve should be sufficiently short to ensure that short-duration, high magnitude events are properly represented.

When Gauge Data Are Not Available: At locations where gauging records are either unavailable or are found to be unrepresentative of the flow regime, it will be necessary to synthesize a flow-duration curve. Two possible methods of doing this are as follows: (a) use records from nearby gauging stations within the same drainage basin, or (b) develop a regionalized flow-duration curve.

The drainage basin flow-duration method relies on the availability of gauging station data at a number of sites on the project stream. Flow-duration curves for each gauging station are derived for the longest possible common period of record. Provided there is a regular downstream decrease in the discharge per unit watershed area, then a graph of discharge for a given exceedance duration against upstream drainage area should produce a power function with insignificant scatter about the best-fit regression line. For example, Figure 2 shows this relationship for the River Wye, UK (Hey 1975). This method enables the flow-duration curve at an ungauged site on that river to be determined as a function of its upstream watershed area.

A regional-scaling method based on data from watersheds with similar characteristics can be used to generate a flow-duration curve for an ungauged site. Emmett (1975) and Leopold (1994) suggest using the ratio of discharge Q to bankfull discharge Q_b as a nondimensional index Q/Q_b to transfer flow-duration relationships between basins with similar characteristics. However,

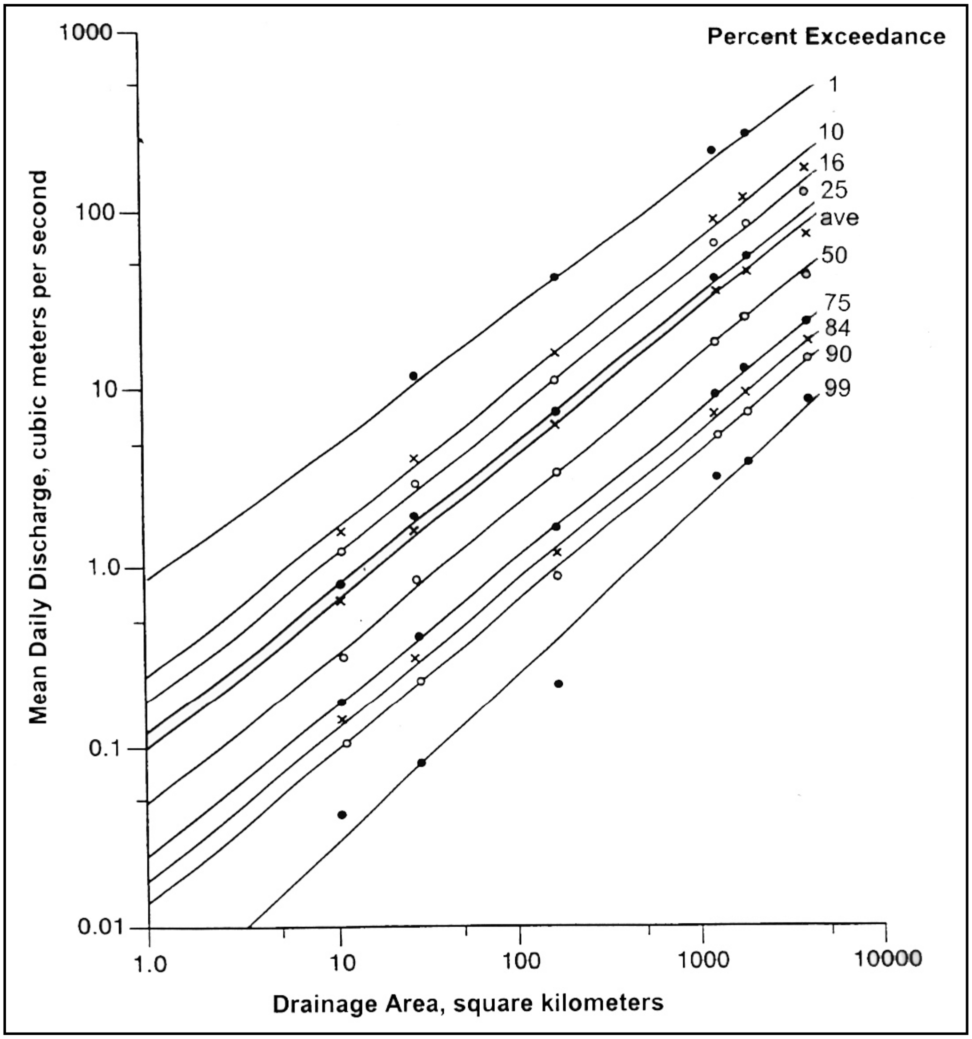

Figure 2. Downstream daily flow-duration curve, River Wye, UK 1937-1962 (Hey 1975)

bankfull discharge does not necessarily have either a consistent duration or return period (Williams 1978). To avoid this problem, a nondimensional discharge index was proposed by Watson, Dubler, and Abt (1997) using the regionalized 2-year discharge Q_2 to normalize discharges as Q/Q_2. For ungauged sites, the 2-year discharge may be estimated from regionalized discharge frequency relationships developed by the United States Geological Survey (USGS) (1993) on the basis of regression relationships between the drainage area, channel slope, and slope length. These relationships are available for most states. The dimensionless discharge index (Q/Q_2) can be used to transfer a flow-duration relationship to an ungauged site from a nearby gauged site. The gauged site may be within the same basin or an adjacent watershed.

A flow-duration relationship can be transferred within a watershed by the following method. First, develop the regionalized flow-duration curve. (Using a flow-duration curve from a gauged site in a physiographically similar watershed, divide the discharges in the flow-duration relationship by the Q_2 for the gauged site. This creates a dimensionless flow-duration curve. If more than one gauge site is available, an average dimensionless flow-duration curve for all the sites can be developed.) Second, compute the Q_2 for the ungauged site. Third, calculate the flow-duration curve for the ungauged site. (Multiply the dimensionless ratios from the regionalized flow-duration curve by the ungauged Q_2.) This flow-duration curve is divided into discharge increments, and an occurrence frequency for each increment is calculated. Hence, this becomes the flow-frequency distribution. The computational procedure for generating a flow-frequency distribution is outlined in Figure 3.

BED-MATERIAL-LOAD RATING CURVE: Sediment data are required to generate the bed-material-load rating curve. These data may be obtained from measurements at a gauging station if the gauge is in close proximity to the project reach and if size-class fractions are provided so that the bed-material portion of the measured load can be determined. A bed gradation from the project reach is required to determine the division between wash load and bed-material load, and to calculate sediment transport if necessary. The wash load should be excluded from the data set used to develop the rating curve. If the bed-material load moves both as bed load and suspended load, then both bed-load and suspended-load measurements are required to determine the bed-material load. If measured data are insufficient, appropriate equations in the SAM hydraulic design package (Thomas, Copeland, McComas, and Raphelt (in preparation); and on the Internet at *http://chl.wes.army.mil/software/sam/*) can be used to generate bed-material loads for selected discharges.

In streams dominated by suspended load, a best-fit regression curve fitted to the data may be adequate to produce a bed-material load function. Frequently this takes the form of a power function:

$$Q_s = a\,Q^b \tag{1}$$

where Q_s is the bed-material-load discharge, Q is the water discharge, a is a regression coefficient, and b is a regression exponent. However, a straight line power function may not be appropriate in all cases. Sometimes, at high discharges the rate of increase in sediment concentration with discharge begins to decrease, especially for the finer sand sizes. In this case it may be necessary to use a different curve fitting function. In coarse bed streams it is likely that a coarse surface layer will develop at lower discharges, significantly reducing sediment transport potential. This process involves both hydraulic sorting of the streambed and hiding of small particles behind bigger particles. Typically, calculated sediment-transport rating curves developed from a single bed gradation will overestimate sediment transport at low discharges. This is probably the most important reason for too much sediment being calculated in the lower discharge class intervals. The computational procedure for generating a bed-material-load rating curve is outlined in Figure 4.

BED-MATERIAL-LOAD HISTOGRAM: The discharges used to generate the bed-material-load histogram are the mean discharges in each arithmetic class in the flow-frequency distribution. The histogram is generated by using the representative discharges and the bed-material-load rating curve to find the bed-material load for each discharge class and multiplying this load by the frequency of occurrence of that discharge class. The results are plotted as a histogram representing the total amount of bed-material load transported by each discharge class during

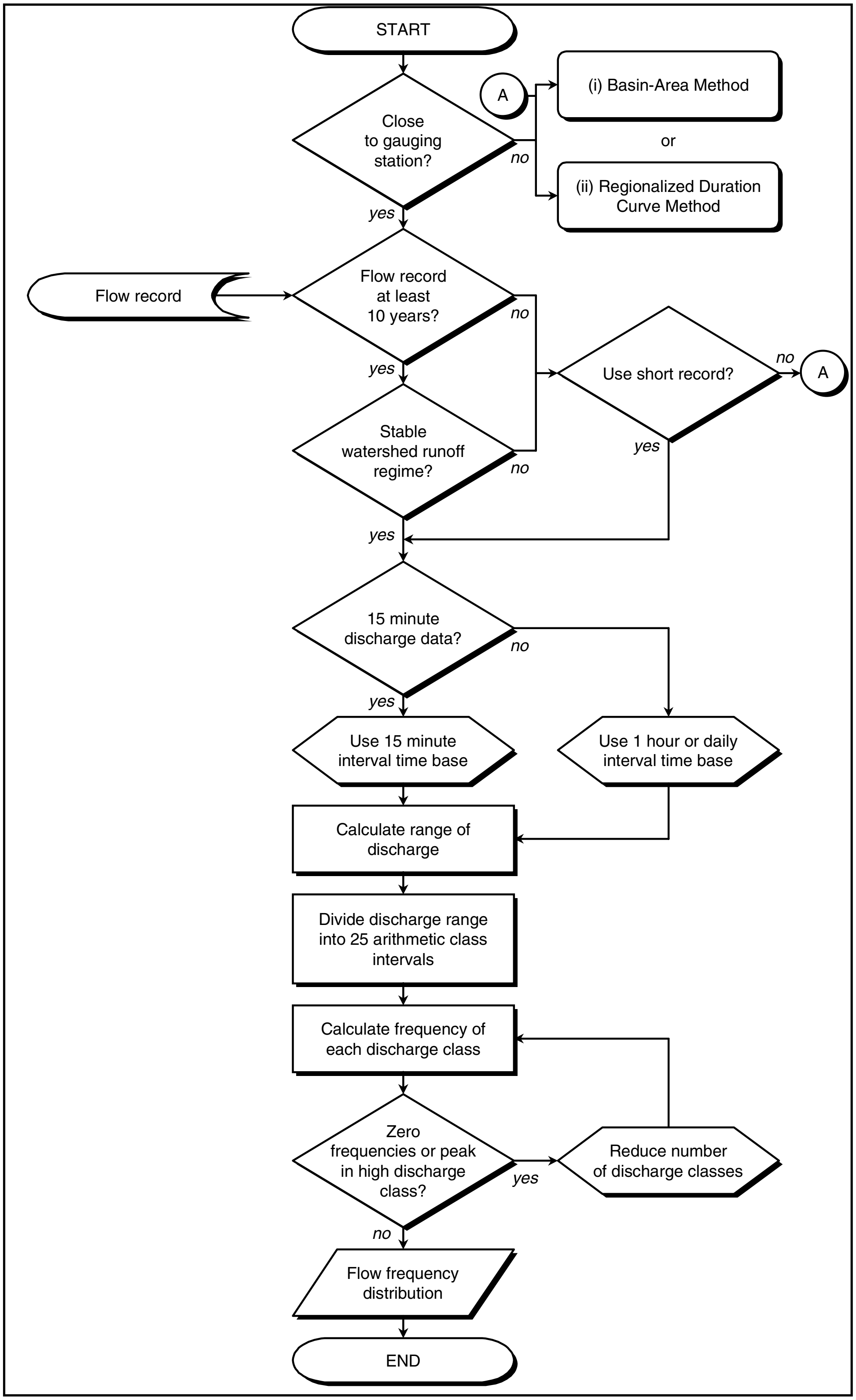

Figure 3. Computational procedure for generating a flow-frequency distribution

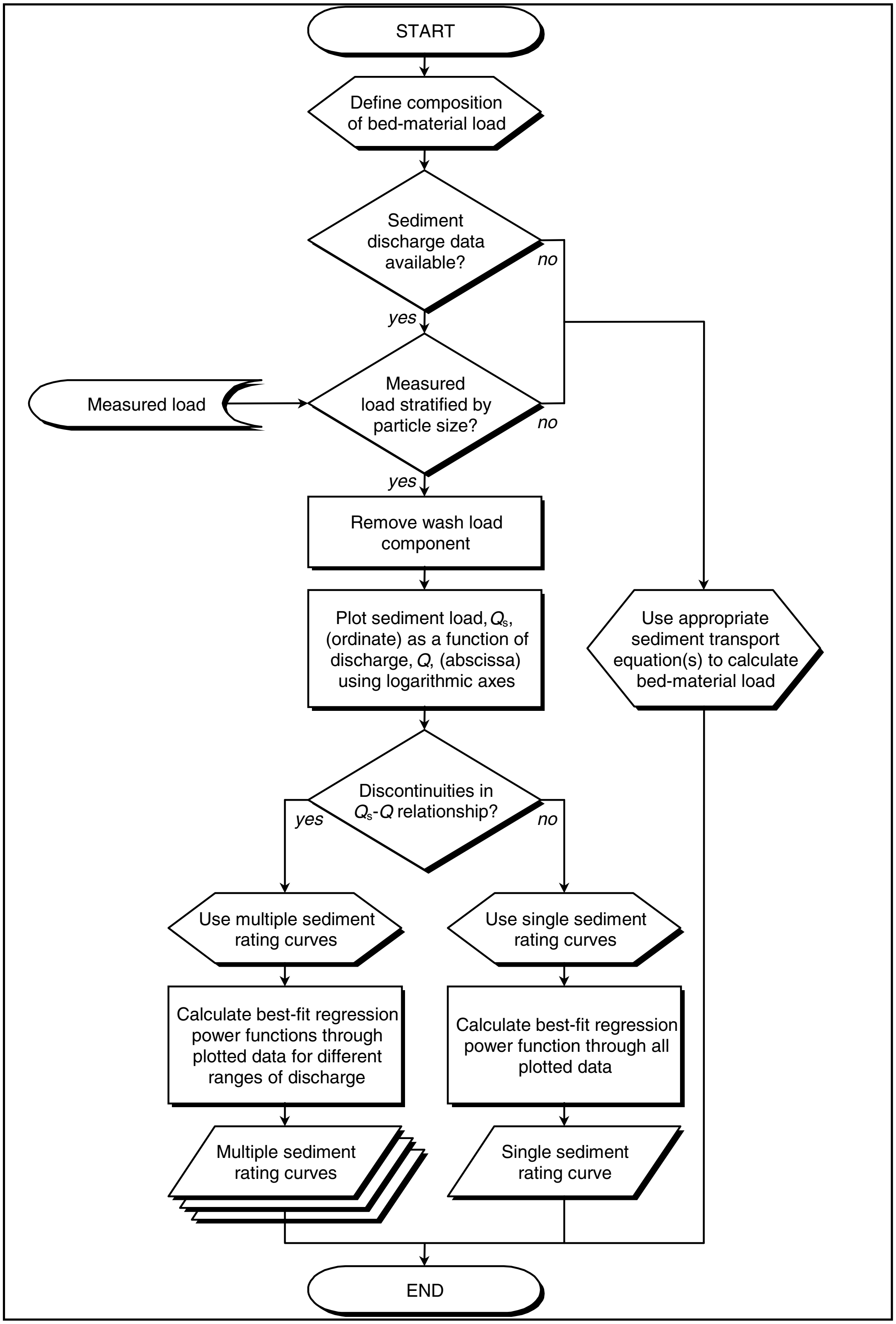

Figure 4. Computational procedure for generating a bed-material-load rating curve

the period of record. This calculation can be completed using the sediment yield routine in the SAM hydraulic design package.

The bed-material-load histogram should display a continuous distribution with a single mode (peak). If this is the case, the effective discharge corresponds to the mean discharge for the modal class (the peak of the histogram). If the modal class cannot be readily identified, the effective discharge can be estimated by drawing a smooth curve through the tops of the histogram bars and interpolating the effective discharge from the peak of the curve. If the modal class of the bed-material-load histogram is the lowest discharge class, it is likely that the indicated effective discharge is erroneous. In this case it may be necessary to modify the procedure by either increasing the number of discharge classes or modifying the bed-material rating curve, noting the cautions to be exercised in each case. The computational procedure for generating a bed-material-load histogram is outlined in Figure 5.

CONCLUDING REMARKS: At the end of the procedure, it is important to check that the effective discharge is a reasonable value for the project reach. This is accomplished by comparing the calculated effective discharge with other discrete approximations of the channel-forming discharge. The return period for the effective discharge is expected to vary between sites depending on the flow and sediment-transport regime of the individual river or reach. For sites where annual maximum series flood-flow data are available, the return period of the calculated effective discharge may be checked to ensure that it lies within acceptable bounds. Experience indicates that it lies within the range 1.01 and 3 years with a preponderance between 1.01 and 1.2 years, regardless of the type of river (Hey 1997). Predicted effective discharge return periods outside the range of approximately 1 to 3 years should be queried.

A further check is to compare the duration of the effective discharge with basin area-flow duration curves. The percentage of time the effective discharge is equalled or exceeded should be compared to the expected range of values reported in the literature. For example, Figure 6 presents a log-log plot of the flow duration of effective discharge as a function of drainage area for several U.S. rivers (Watson, Dubler, and Abt 1997). The graph can be used to assess whether the duration of the effective discharge computed using the method described in this Technical Note is comparable to the results of other studies. It is not intended that this graph be used to predict effective discharge as a function of drainage area, as large errors are likely to result from this application.

Finally, a morphological check should be undertaken to compare the effective discharge to the bankfull discharge. This is best performed by identifying the bankfull stage at a stable cross section and calculating the corresponding discharge either from the stage-discharge relationship at a nearby gauging station or using the slope-area method.

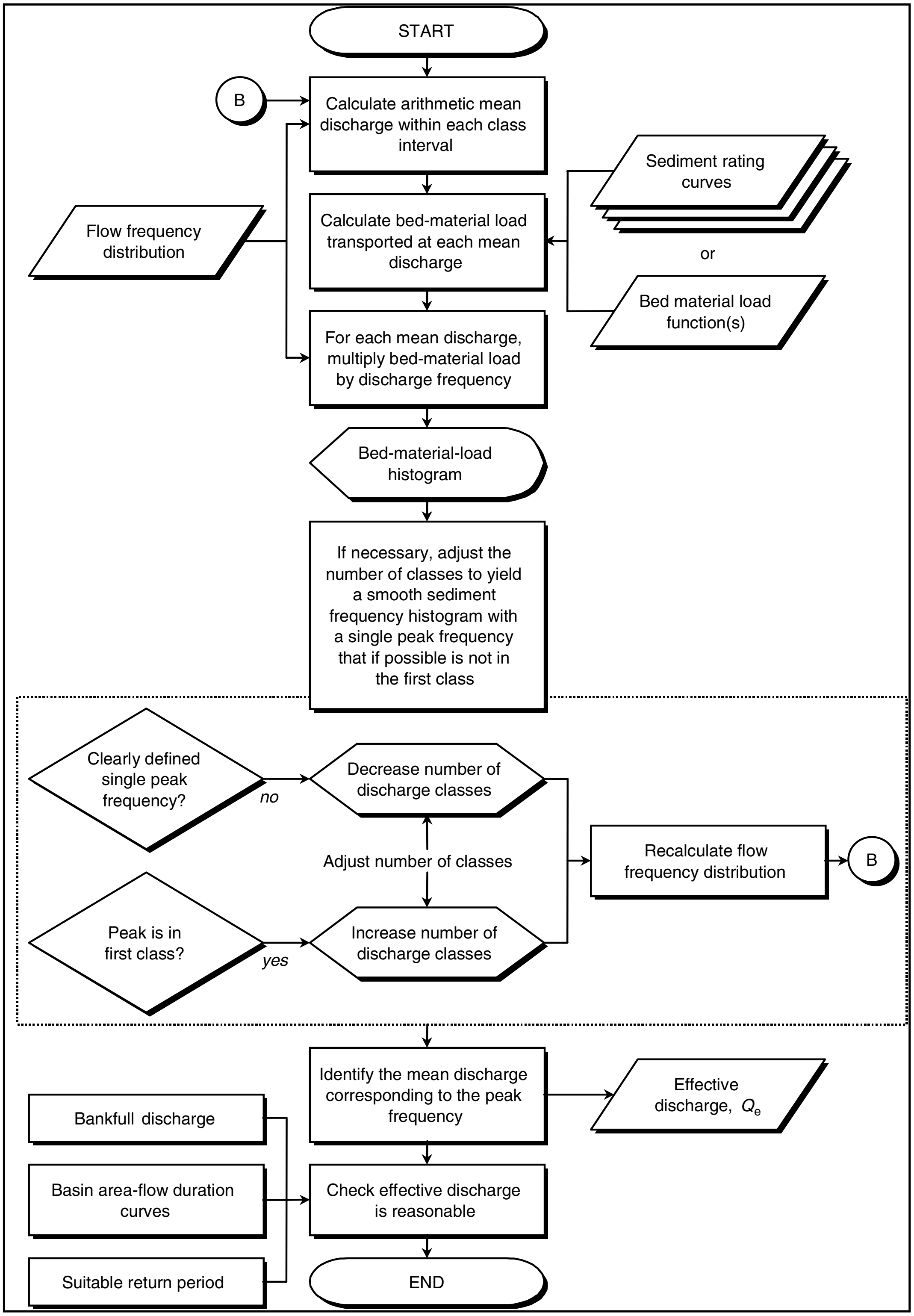

Figure 5. Computational procedure for generating a bed-material-load histogram

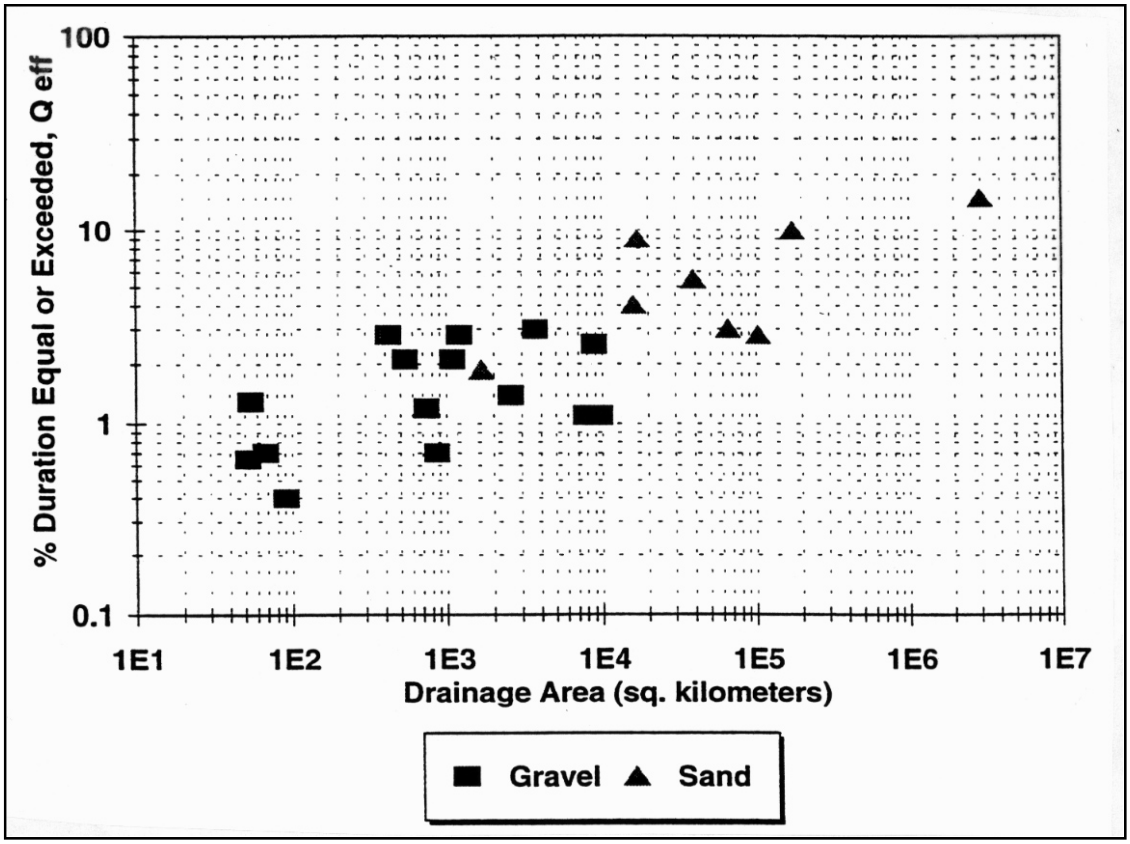

Figure 6. Effective-discharge duration versus drainage area

ADDITIONAL INFORMATION: This Technical Note was extracted from Biedenharn et al. (in preparation). Additional information may be obtained from Dr. D. S. Biedenharn, Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center (ERDC), 3909 Halls Ferry Road, Vicksburg, MS 39180, at 601-634-4653 or e-mail *David.S.Biedenhard@erdc.usace.army.mil;* or Dr. R. R. Copeland, Coastal and Hydraulics Laboratory, U.S. Army Engineer Research and Development Center (ERDC), 3909 Halls Ferry Road, Vicksburg, MS 39180, at 601-634-2623 or e-mail *Ronald.R.Copeland@erdc.usace.army.mil*.

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