Chapter VI

TOTAL POTENTIAL SEDIMENT

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INTRODUCTION

One of the most significant and frequent water quality changes resulting from silvicultural activities is accelerated, inorganic sediment discharge. Land and stream systems are constantly adjusting to changes in the erosional rates of slopes and the transport capabilities of the stream systems draining those slopes. Silvicultural activities can exponentially affect the rate of sediment discharge, depending upon the sensitivity of the slopes and the affected stream reaches and the degree and duration of impact.

It is difficult to predict absolute changes because of the time-space variability inherent in stream systems; however, several consistent analytical relationships involving the prediction of sediment supply and transport are available. These relationships can be used to estimate relative amounts of change in potential sediment discharge resulting from proposed silvicultural activities.

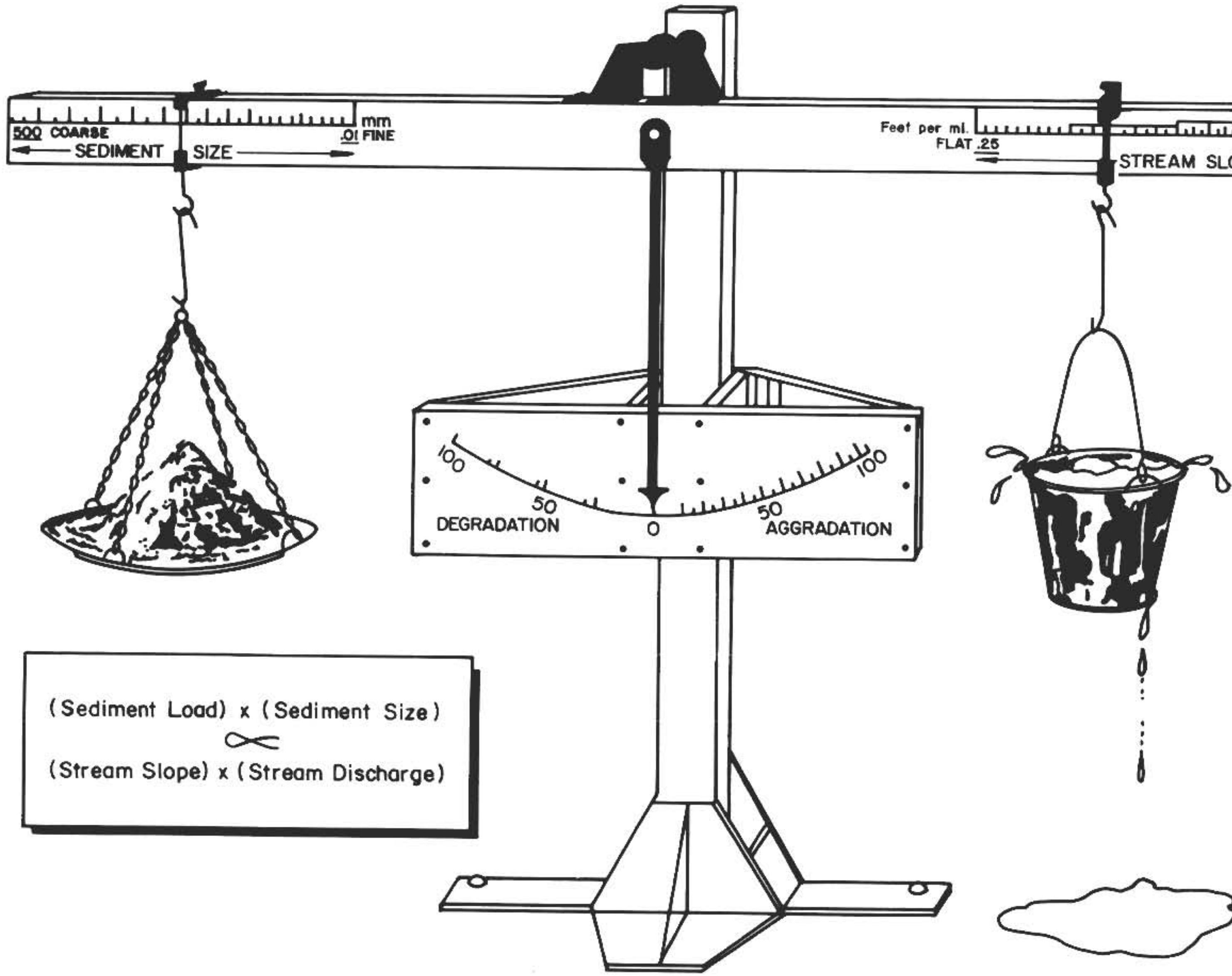

Figure VI.1.—Diagrammatic relationship of a stable channel balance (Lane 1955).

DISCUSSION

In most cases, sediment objectives are stated in terms of acceptable increases in suspended sediment based on state and federal laws and physical site conditions. The analysis procedure estimates the amount of potential change in suspended sediment discharge and bedload sediment discharge as well as qualitative effects on channel stability.

Evaluation of potential sediment changes requires use of analytical procedures to make a consistent comparative analysis of baseline and accelerated levels. The procedures outlined in this handbook are not designed to predict absolute values obtained for any given year. They do however relate to the potential changes in the physical processes, as affected by silvicultural activities. The interpretation made from the results of theses analyses requires a great deal of professional judgment.

STREAM CHANNEL MORPHOLOGY AND WATER QUALITY

Streams are dynamic systems where configurations are adjusted in response to eight interrelated variables — width, depth, gradient, velocity, roughness of bed and bank materials, discharge, concentration of sediment, and size of sediment debris (Leopold and others 1964). A change in one or more of the eight noted variables produces changes in channel processes with a net effect of either aggradation or degradation. However, a counteractive change occurs over time in the other variables to prevent continued stream aggradation or degradation (Shen 1976).

When a stream system is in a state of dynamic equilibrium, the eroded material supplied to and stored in the stream is balanced with the energy available to transport the material. As changes affect sediment supply and stream energy, the channel system undergoes a series of adjustments and is in disequilibrium. Under wildland watershed conditions, dynamic equilibrium is not a steady state from year to year, and annual variations in scour or deposition may occur. These channel adjustments not only affect channel stability, but generally result in significant changes in sediment discharge.

Lane (1955) diagrams a stability relationship between sediment supply and stream energy (fig. VI.1), indicating stream slope and discharge (energy) are proportional to sediment load and sediment size (supply). Process changes which affect stream slope, stream discharge, sediment size and concentration may create unstable conditions which can result in stream channel aggradation and/or degradation.

Shen and Li (1976) describe a relationship where sediment discharge is a function of the supply rate and transport capability of various sized particles under a particular flow regime (fig. VI.2). "Washload" is that portion of the suspended load which is 0.0625 mm or smaller (silts and clays).

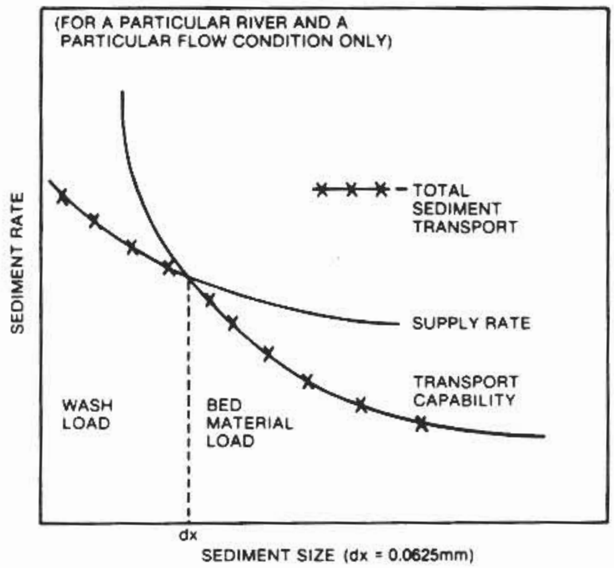

Figure VI.2.—Relationships of sediment rate and size to supply rate and transport capability (Shen and Li 1976).

Man-caused changes in channel process include increased debris, constrictions due to road fill encroachments, stream crossings, alterations in streamflow amounts and timing through vegetation modifications, introduced sediment, and direct channel alterations. These impacts affect the rate and magnitude of channel adjustments and may affect channel erosion through lateral channel migration, change in bed form, and other morphological changes. Such changes are ultimately expressed as differences in sediment concentration per unit discharge and as changes in bedload transport.

The ability of streams to adjust to imposed changes varies with the type of bed and bank materials, the stability of the landform in which the stream is incised, the amount and size of sediment in the channel, the hydraulic geometry of the channel, and the runoff characteristics of the watershed.

Stream channels reflect the current watershed condition. The stability of natural channels varies by geomorphic province and by reach within the same watershed. The ability to interpret this variance in stability is important when assessing sediment discharge influenced by channel processes. A stability evaluation provides a consistent analytical comparison of stability between stream reaches within a given region and is a reproducible method of assessing channel characteristics. Stability evaluations (Pfankuch 1975) examine primarily: (1) detachability of bank and bed materials, (2) availability or supply of sediment as a function of degree of entrenchment, stored sediment, and landform adjacent to the stream, (3) direct impacts on the channel, and (4) energy forces available. Examples of streams with various stability ratings are provided in appendix VI.A.

Suspended Sediment

Suspended sediment is defined as that portion of the total sediment load in transit under varying flow regimes that is measured using depth-integrated samplers (DH-48, DS-49, 59) as described by Guy and Norman (1970). This procedure, utilizing the equal transit rate method, requires a continuous sample taken from the water surface to within 3 inches of the stream bed. Sediment size generally includes sands or smaller, but a specified size is not always predictable due to changes in stream velocities.

Suspended sediment from stream channel erosion is the major contributor to total annual sediment discharge in some streams draining forested watersheds (Anderson 1975, Striffler 1963, Rosgen 1973, Flaxman 1975, and Piest and others 1975). The sediment rating curve has been developed and used for analyzing sediment discharge for the past 40 years. A sediment rating curve is derived from values of measured suspended sediment, in milligrams/liter, correlated with stream discharge (cfs). Sediment rating curves represent changes in sediment supply and stream channel adjustments associated with the accelerated sediment introduction.

Recent applications and interpretations of the sediment rating curve approach have been used in management applications (Flaxman 1975 and Rosgen 1975a). This latter interpretation of the sediment rating curve technique is presented for use in this chapter. The sediment rating curve approach involves depth-integrated sampling for suspended sediment over a wide range of climatic situations and representative flows. Examples of typical sediment rating curves are shown in figures VI.3 and VI.4.

Most of the annual sediment discharge results from streamflow that generally occurs less than 10 percent of the time. Since streamflow is the primary variable associated with stream energy, changes in flow amounts or timing directly influence sediment discharge. Although flows vary from year to year, time-dependent plots generally are not evaluated because long-term records are required. However, flow-dependent analysis can be made based on representative flows monitored over a water year (October 1 through September 30), where variables affecting sediment concentrations are determined concurrently with stream discharge. Sampling "representative flows" involves collection of suspended sediment during various flow and seasonal conditions to detect any variability in concentration for the same flow during a water year. Significant variability can be analyzed separately. Sampling intensity depends on flow variation and anticipated supply changes. Minimum sampling stratification for the development of sediment rating curves is shown in step 3 of the procedure.

If the representative flows cannot be sampled to establish a sediment rating curve, continued monitoring into the next water year may be required. The reliability of the procedure may be reduced if representative flows, as defined, are not sampled.

The many research efforts utilizing the sediment rating curve approach are summarized in the USFS-EPA "Non-Point Water Quality Modeling, Wildland Management" (1977). Flaxman (1975) used this approach to determine the amount of channel erosion attributable to man's activities. Applications by Farnes (1975) were designed to identify changes in sediment discharge as a result of upstream changes in land use on selected watersheds in Montana. The technique is presently used as a portion of the analytical prediction techniques for determining potential changes in sediment due to timber harvest on some national forests in Montana and Idaho (USDA Forest Service 1975).

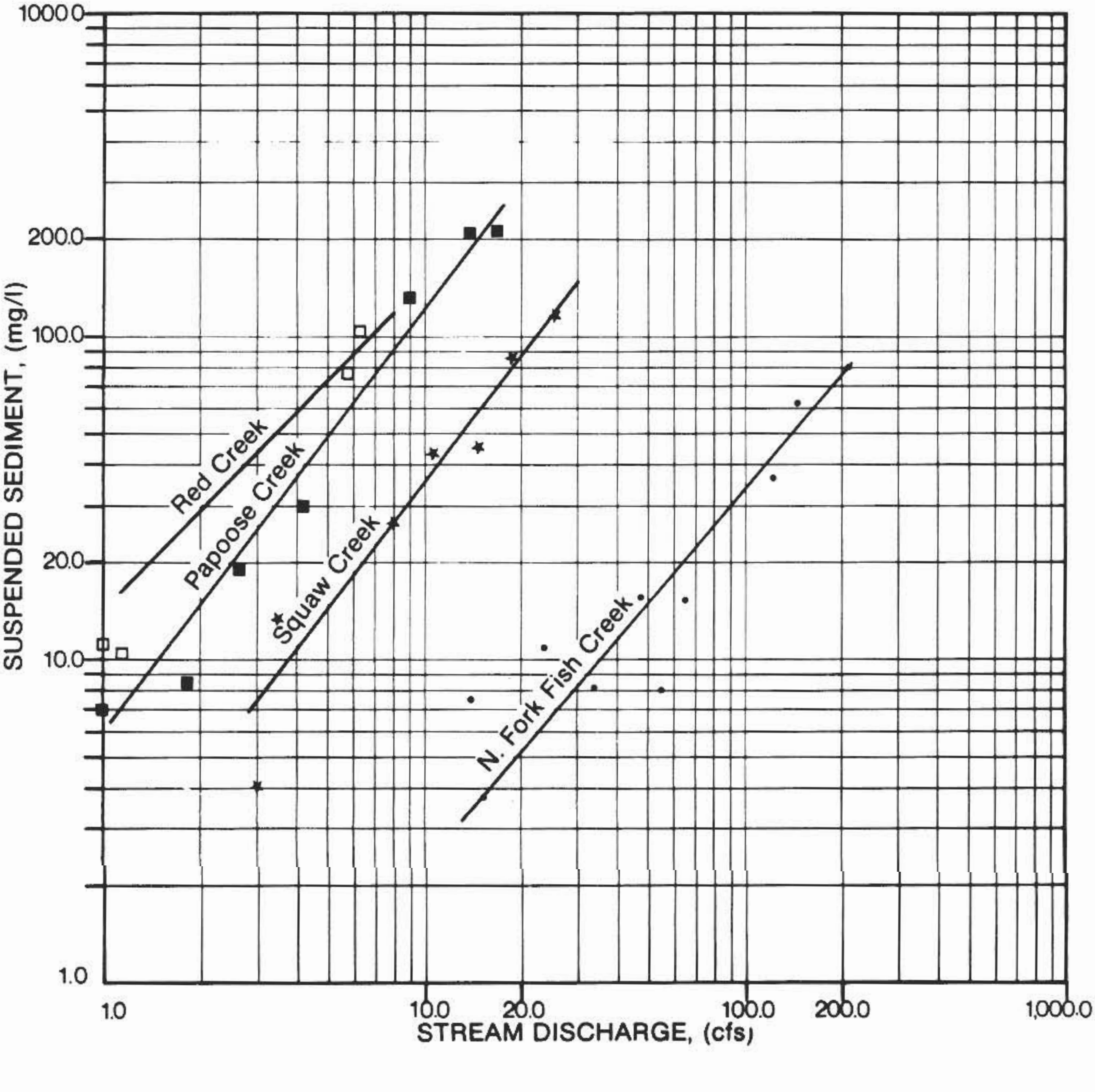

Figure VI.3—Sediment rating curves for streams in western Wyoming (Holstrom 1976).

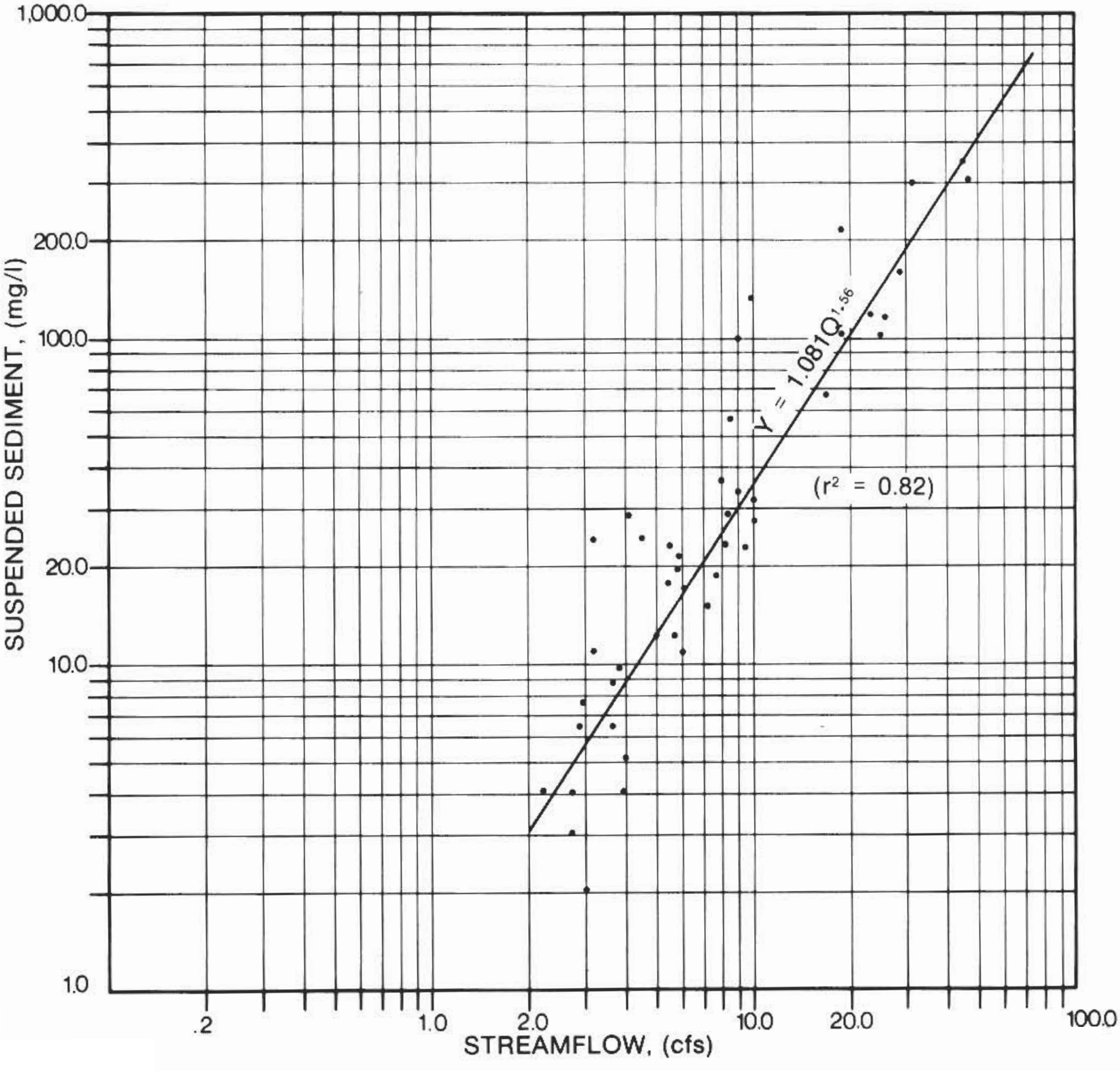

Figure VI.4.—Sediment rating curve for Needle Branch Creek, Oregon, 1964-1965 water year (Sundeen 1977).

Interpretations Of Sediment Rating Curves

Shifts in the sediment rating curve reflect both natural and man-induced changes that alter the slope and intercept of the regression equation. These shifts indicate the dynamic nature of stream channels.

Examples of changes in sediment rating curves have occurred following a major flood in 1964, which shifted the sediment rating curve a full order of magnitude on the Eel River in northern California (Flaxman 1975). Thus, an increase in stream channel sediment supply that aggraded many river reaches resulted in major channel adjustments and associated increased sediment discharge (fig. VI.5).

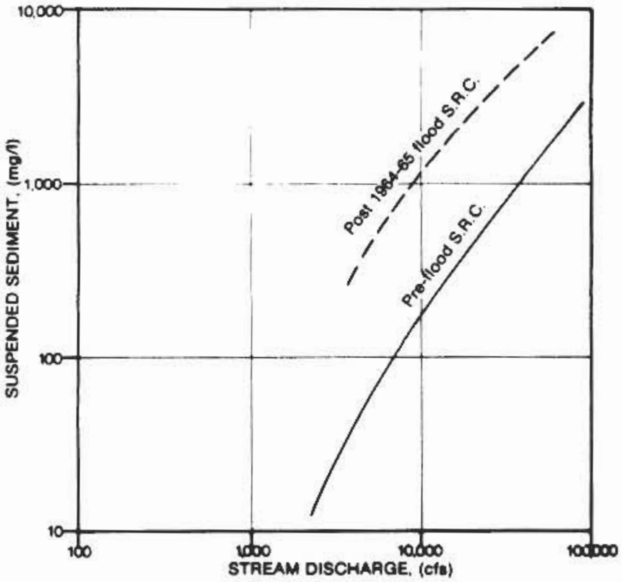

Figure VI.5.—Change in the sediment rating curve for the Eel River, Scotia, Calif., showing increases in sediment concentration per unit discharge when flood caused a change in sediment deposition (Flaxman 1975).

For any given flow on the Eel River following the flood, the sediment concentration was exponentially higher. Suspended sediment discharge under post flood condition is very sensitive to flow increases. Flaxman (1975) cited similar results from channel restoration measures applied to streams where channel erosion was a predominant source of the total annual suspended sediment discharge.

An analysis of the effects of clearcutting on sediment rating curves was recently conducted on the Needle Branch drainage, near the Oregon coast (Sundeen 1977). This analysis indicated a shift of the regression constants of the sediment rating curve following the first year of harvest (fig. VI.6). Even though the highest flood peaks occurred before harvest (due to the 1964 flood), the major shift in the sediment rating curve occurred following timber removal. The recovery of Needle Branch has been fairly rapid; in the second year following clearcutting, the sediment rating curve (1967-68) returned nearer the pre-flood condition. Under the post-flood condition, any further change in duration of bankful stage or in magnitude of peak flows due to timber harvesting will produce exponentially higher sediment discharge. These relationships agree closely with those suggested by Flaxman (1975).

The sediment rating curve technique has been used to evaluate timber sale impacts in Montana and Idaho (Rosgen 1975a). Changes in sediment supply were linked to individual sources when a surveillance monitoring program was initiated to show these "shifts" in sediment rating curves. In many instances, the major cause for the shifts and change in stability was associated with sediment supply increases by roads, debris slides and increases in stream discharge. Stream channel impacts can be evaluated through relationships developed between measured sediment rating curves and stream channel stability as explained in appendix VI.B.

Time Series Analysis-Recovery

Conceptually, it is desirable to predict not only the magnitude and direction of change in sediment rating curves, but also the time required for the sediment rating curve to return to its predisturbance position. However, it is beyond the state-of-the-art to actually predict a post-silvicultural activity sediment rating curve. Despite this, it is of value to qualitatively evaluate recovery to help interpret analysis results.

A qualitative procedure for determining the recovery potential of streams by morphological descriptions was developed and used in northern Idaho (Rosgen 1975c). It evaluates recovery potential based on depth of channel to bedrock, gradient, material size, and channel stability ratings. The recovery period is based on the type and dates of impact from historical records on various streams, differing channel materials, gradients, etc. Tested quantitative techniques for determining recovery periods and rates at which the sediment rating

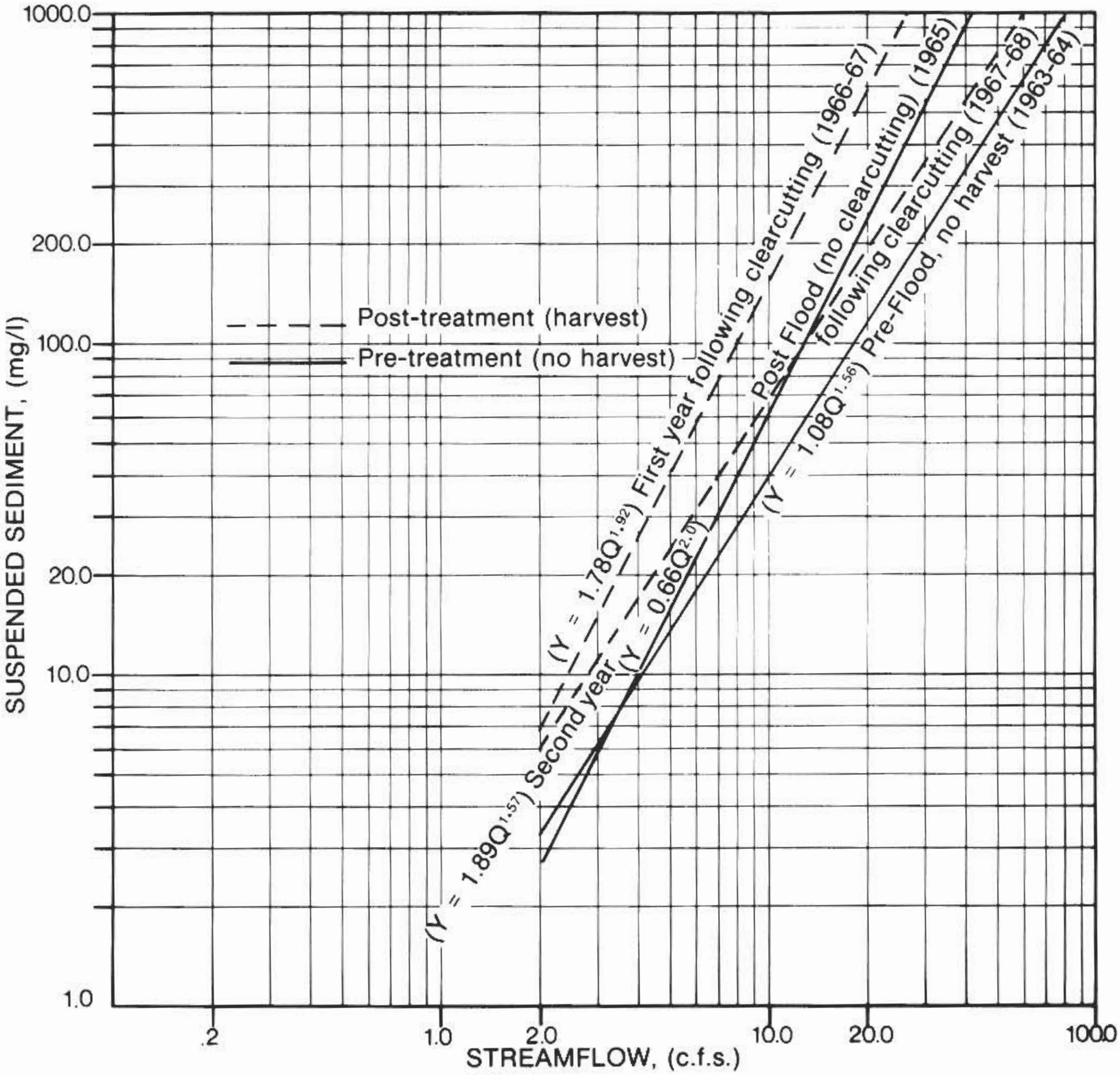

Figure VI.6.—Change in sediment rating curves for Needle Branch Creek, Oregon, showing the shift in rating curves due to 1964 flood and silvicultural operations (Sundeen 1977).

curves return to pre-silvicultural activity conditions have not been developed. A technique that may have potential application is presented in appendix VI.C. Any recovery technique should be developed locally, because great variation can be expected in regional relationships of recovery response.

Turbidity

Turbidity is an optical characteristic of water quality, whereas suspended and bedload sediment are related to the actual rate and weight of transported inorganic soil particles. It is often possible to establish a correlation between turbidity and suspended sediment concentration. A relationship can be established using regression analysis based on local data if the analysis is: (1) conducted on the same stream reach under a wide range of flow conditions, and (2) conducted so that the turbidity sample is also depth integrated. If significant correlations can be established between the two water quality characteristics, one may be inferred from the other. Turbidity will not be directly analyzed in this chapter.

Bedload Determination

Bedload is inorganic soil particles of various sizes which are transported in contact with or near the streambed. Bedload transport becomes a predominant factor during major runoff events, where sufficient energy is available to dislodge and transport the larger sized particles generally armored in the streambed or supplied to the stream from the channel sides and slopes. Studies of mountain streams in northern Idaho have shown bedload to be less than 5 percent of mean annual total sediment discharge when measured concurrently with suspended sediment on first to third order streams (Rosgen 1974). Emmett (1975) determined that bedload transport for gravel bed streams in the upper Salmon River area was approximately 1 to 10 percent of the suspended sediment load transported. However, evaluation of the basic processes involved in bedload transport is valuable to determine the potential changes in stream channel stability and in associated suspended sediment concentrations.

Numerous empirical bedload transport equations are described in the EPA-USFS "Non-Point Water Quality Modeling Wildland Management" (1977). However, data for validation of natural channels and for testing these bedload transport equations are limited; therefore, it is difficult to convert them to quantitative expressions of water quality.

Evaluation Of Bedload Discharge Using Bedload Rating Curves

The procedure presented in this chapter requires bedload sampling concurrent with suspended sediment sampling. The method for establishment of bedload rating curves is similar to the procedure for developing suspended sediment rating curves. Bedload is measured from the bed surface to 3 inches above the bed using a pressure differential type sampler (Helley and Smith 1971) during representative flows in 1 water year. An example of a bedload rating curve is shown in figure VI.7.

The calculations utilizing the bedload rating curve procedure are designed to:

1. Predict a quantitative change in bedload sediment discharge by comparing changes in amounts and seasonal distribution of excess water;
2. Determine the relative contributions of suspended and bedload sediment;
3. Provide data to develop local bedload-stream power relationships to assess potential stream channel changes and resulting changes in bedload sediment discharge.

Effects Of Bedload Changes On Stream Channels And Sediment Discharge

The potential impact on stream channels due to introduced sediment and/or changes in stream power is calculated using procedures similar to those presented by Leopold and Emmett (1976). This requires the development of regional or local bedload stream power relationships expressed as a function of the size of material being transported (fig. VI.8). At high flows, transport rates become directly proportional to stream power, as suggested by Bagnold (1966). This is shown in figure VI.8, where the ratio of transport rate (i_b) to unit stream power (ω) is represented as $i_{b/\omega}$ = 100%. Stream power, as used in the proposed method, is defined as the unit weight of water (1,000 kg/m^3) times the discharge of water (m^3) per meter width over the total stream width (m) times the gradient of the

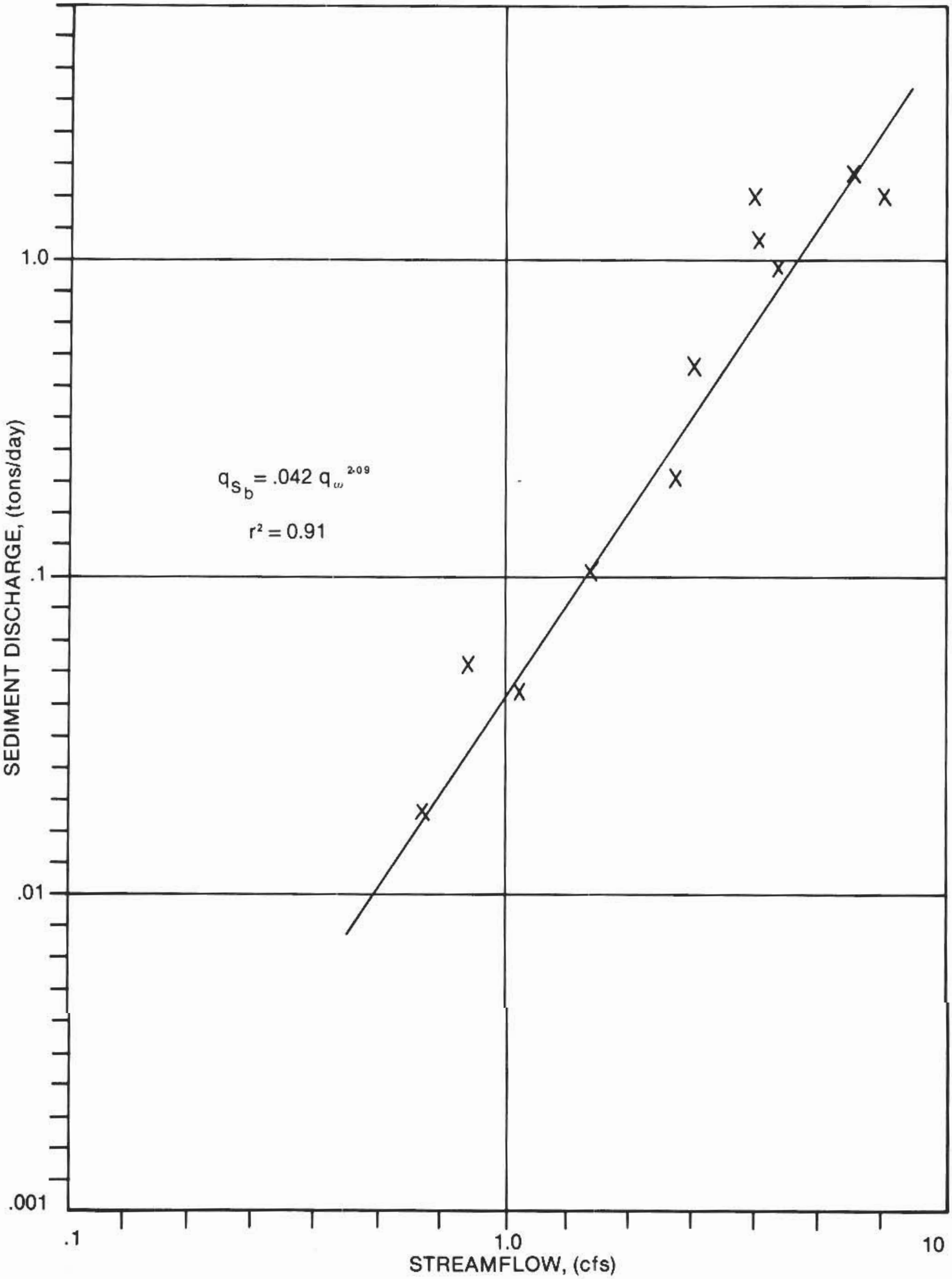

Figure VI.7.—Bedload rating curve, central Idaho stream (Megahan 1978).

stream (m/m) (Leopold and Emmett 1976). The integration of cross-sectional area and velocities assumes rectangular banks for the calculation. To develop this relationship, it is necessary to measure particle size of transported material, water surface slope, stream discharge, and stream width.

The locally derived stream power-bedload transport rate relationship should be calculated using the same principles as in the regression relationships of suspended sediment and bedload transport to streamflow.

The objective is to estimate the potential for stream channel scour and/or deposition caused by direct impacts that change the stream power variables (surface water slope and bankful width). Introduced potential sediment volume and particle size from soil mass movement are qualitatively evaluated, based on the available stream power and related sediment transport rates under bankful discharge.

Effects Of Direct Channel Impacts On Bedload Sediment Discharge

Effects of silvicultural activities on the stream power variables and associated sediment transport can be calculated. Activities that change local surface water slope, discharge, and bankful stream width can be affected by stream channel encroachment of road fills, logging debris, and stream crossings. Potential changes in bedload transport are obtained through calculations involving relationships similar to those depicted in figure VI.8.

Field evaluations of channel alterations resulting from certain silvicultural activities will provide information on changes in stream width and surface water slope as measured above versus below channel impact areas. A change in stream power (assuming no change in sediment supply) would result in a direct change in bedload discharge.

Effects Of Sediment Supply Changes And Stream Power Reductions On Stream Channels

Channel effects caused by introduced sediment from soil mass movement may be evaluated using the bedload transport rate-stream power relationship on the stream reach directly below the source. A calculation involving bankful discharge, bankful width and surface slope determines the instantaneous maximum bedload transport rate. Sediment deposition in the channel may result if the potential delivered soil mass movement volume and change in particle size exceeds the maximum potential transport rate under a given stream power.

A calculation involving bankful discharge is needed if extrapolation of the bedload transport rate-stream power relationship is needed above the third order reach. Riggs (1976) presents a procedure for determining bankful discharge. This approach involves a relationship between stream slope and velocity, eliminating the need to estimate a roughness coefficient to obtain velocity. The bankful stage determination uses procedures documented by Williams (1977), where a channel configuration indicating a bankful stage is observable on the upper limit of the "active floodplain."

A reduction in stream power caused by a debris dam would yield lower transport rates. Assuming no reduction in sediment availability, the differences in sediment yield may result in local deposition or stream aggradation. The potential for deposition or aggradation is evaluated in the detailed procedures recommended in this chapter. Until such benchmark references or long-term data can be collected and analyzed, only qualitative predictions of stream channel changes can be made.

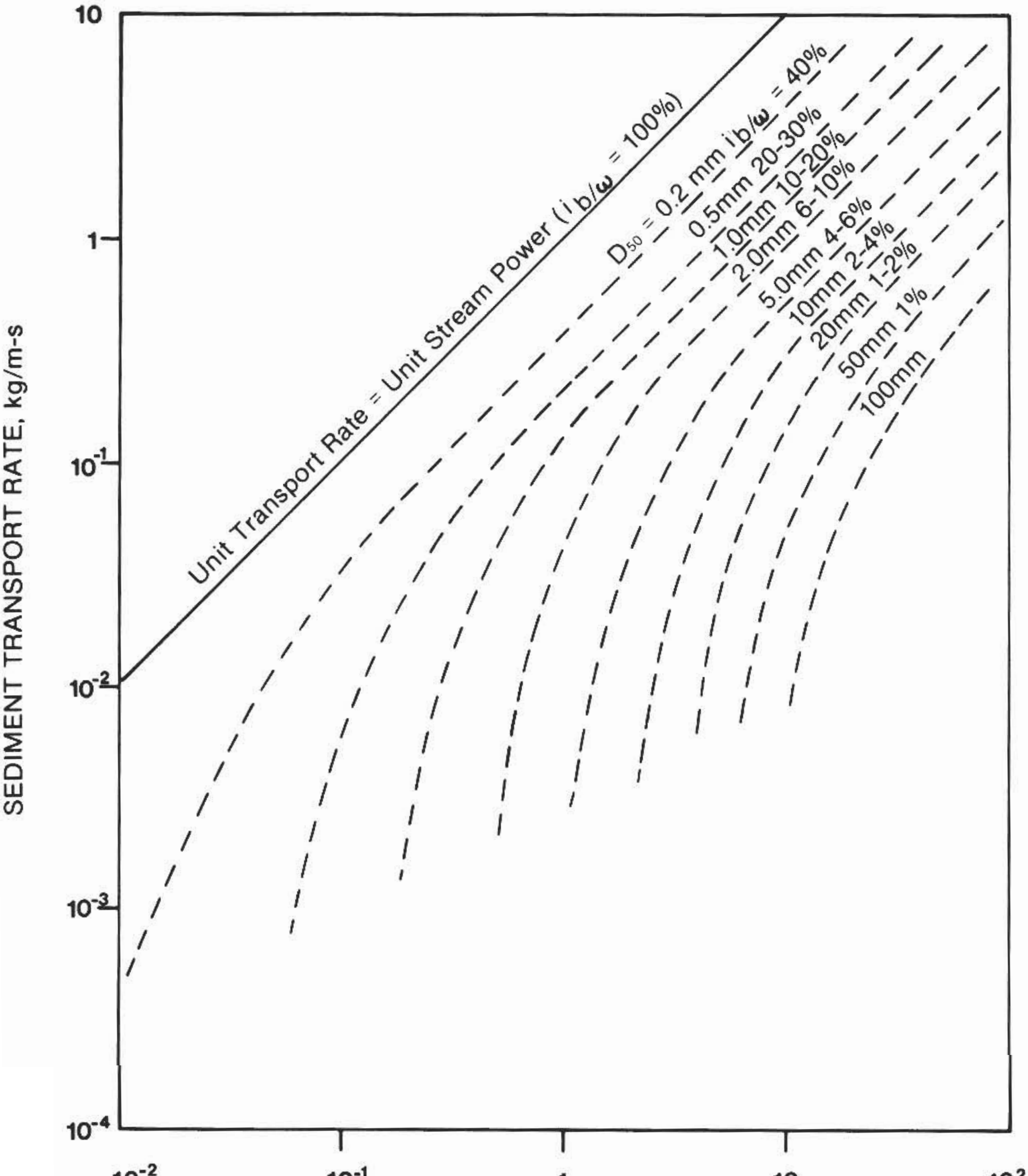

Figure VI.8.—Relationship of bedload transport and stream power for the East Fork River, Wyoming (Leopold and Emmett 1976).

THE PROCEDURE

The analysis procedure for determining potential changes in total sediment discharge is sequentially diagrammed in the procedural flow chart, figure VI.9. The following stepwise procedural description and discussion correspond with the procedural flow chart and provide directions for completing the analysis. Worksheets provided for the analysis are referenced where applicable. Table VI.1 provides a summary of all data input required to use the total sediment discharge procedure.

The following assumptions are inherent in this analysis procedure:

1. No distinction will be made between material detached from the channel banks and that previously deposited on the streambed and channel bars which is available for redistribution under varying flow regimes.
2. Increases in stream discharge exponentially increase suspended sediment and bedload sediment. Statistical relationships can be established for sediment rating curves.
3. Suspended sediment rating curves represent the existing relationship between sediment availability and stream discharge for a particular stream reach and watershed area. Temporal and spatial distribution of sediment is not addressed in this procedure. For the purpose of this analysis, temporal and spatial distribution of sediment is assumed to be constant.
4. The procedure is applicable to watershed basins of third order size.
5. The size of material delivered to streams from surface erosion is assumed to be silt and clay (washload) or smaller than .0625 mm.
6. All of the introduced washload sediment is transported through individual stream reaches (i.e., no storage is calculated, and the stream has sufficient energy to transport this sediment size).
7. A relationship can be developed between sediment transport rate and stream power through measurements of stream slope, discharge, bedload transport rate, and particle size (D_{50} = particle size for which 50 percent of the sediment mixture is finer).
8. Water surface slope does not change with water surface elevation (stage).

The prediction techniques presented in the analysis section are not recommended to replace local data or transport prediction capability, when they are available. The analysis provides the basic process relationships needed for evaluation until local data become available. A monitoring program to measure pre- and post-silvicultural activity sediment concentrations for the various flow regimes would help verify the sediment discharge predictions. Baseline channel geometry surveys should also be conducted to determine changes in stream aggradation or degradation, lateral migration, or other channel adjustments.

It is important to notice that all the calculations through step 20 are designed to relate quantitatively to the potential sediment discharge at the third order reach. Step 21 is a qualitative interpretation for various reaches in the subdrainage as affected by stream channel response to introduced sediment from soil mass movement, and channel encroachments.

DETAILED ANALYSIS PROCEDURE

Step 1. Subdrainage and Stream Reach Characterization

Procedure: Select a representative third order stream reach where data collection is required.

Discussion: For quantitative evaluations (steps 1-20) this stream reach will be used. For qualitative evaluation (step 21), individual first through third order streams will be selected.

Step 2. Determination of Pre- and Post-Silvicultural Activity Hydrographs or Flow Duration Curves

Procedure: Obtain the output from the hydrologic analysis for the selected third order drainage as outlined in chapter III. Outputs required are:

a. Potential increase in total annual water production;
b. Seasonal distribution of water (based on 6- or 7-day averages) (figs. VI.10a or VI.10b) represented as either hydrographs or flow duration curves for:

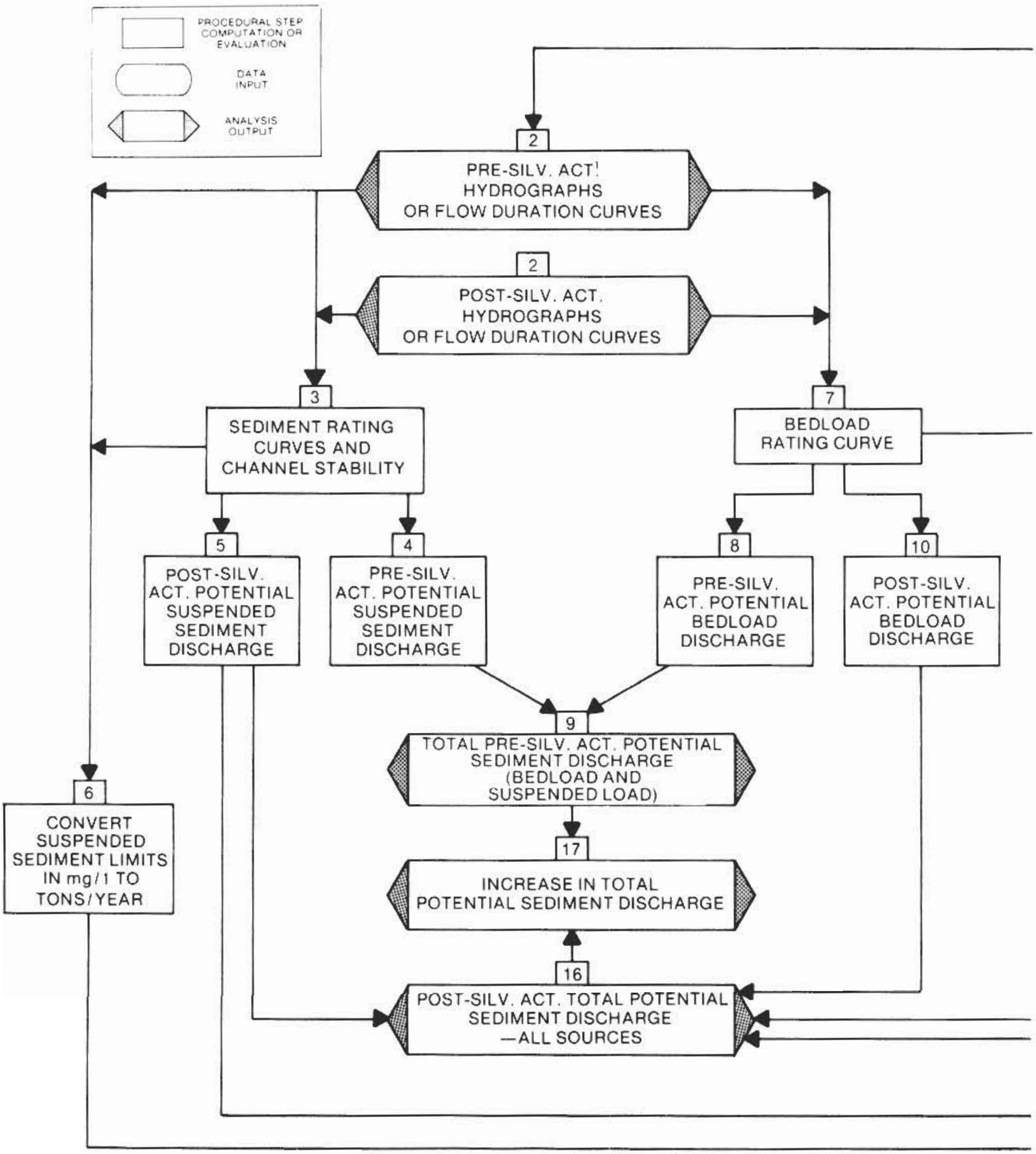

Figure VI.9—Procedural flow chart for estimating potential changes in total sediment discharge.

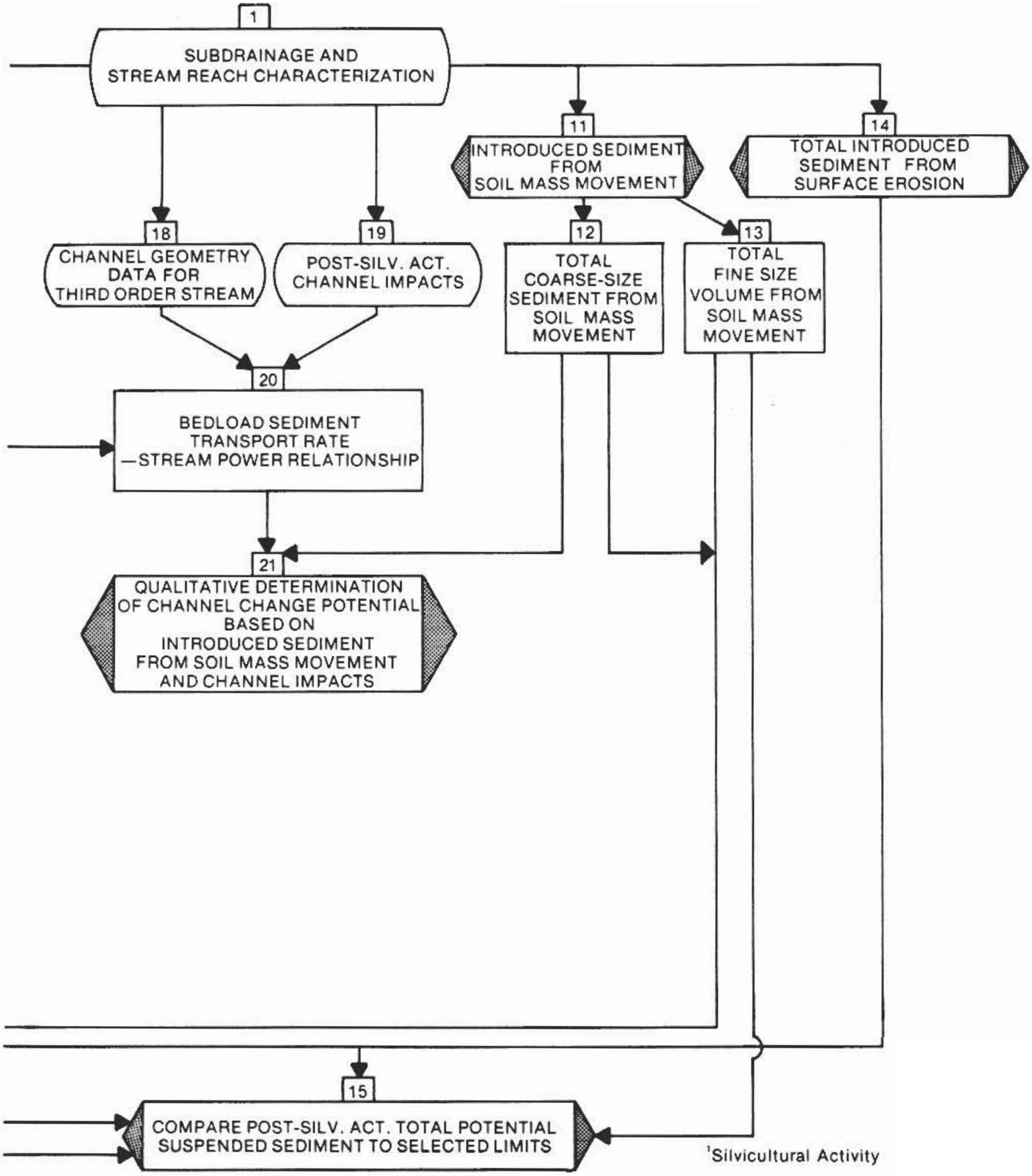

Figure VI.9—continued

Table VI.1.—Summary of input required to use the total sediment discharge procedure.

Data requirements	Procedural steps 1	2	3	4	5	6	7	8	9	10	11	12	13	14	15	16	17	18	19	20	21
Aerial photography and stream reach selection	x																				
Pre-silvicultural activity hydrographs		x		x		x		x													
Post-silvicultural activity hydrographs		x			x					x											
Measured suspended sediment (mg/l)			x	x	x	x															
Measured stream discharge (cfs)			x	x	x	x	x	x		x											
Measured bedload sediment (tons/day)							x	x		x											
Allowable maximum sediment concentration (from water quality objective) (mg/l)						x															
Fine particle size from soil mass movement source (ch. V) (tons)											x		x								
Coarse particle size from soil mass movement source (ch. V) (tons)											x	x									
Surface erosion (ch. IV) (tons)														x							
Bankful stream width (ft)																					x
Bankful surface water slope (ft/ft)																					x
Bankful depth (ft)																					x
Bankful discharge (cfs)																					x
Measured width from measured third order stream discharge (ft)																		x		x	
Measured depth from measured third order stream discharge (ft)																		x		x	
Measured surface water slope from measured third order stream discharge (ft/ft)																		x		x	
Predicted change in width with post-silvicultural activity																			x		
Predicted change in surface water slope with post-silvicultural activity																			x		

(1) baseline condition (pre-silvicultural activity)

(2) existing condition (pre-silvicultural activity)

(3) proposed condition (post-silvicultural activity).

Discussion: Distribution estimates of excess water both before and after silvicultural activity are required to determine changes in both suspended sediment and bedload discharge. If a particular short duration stormflow response is responsible for the majority of the sediment discharge in a particular reach, a shorter duration (less than 7-day) analysis will increase the sensitivity for flow related sediment transport calculations. Thus, the user may specify a local hydrologic evaluation, which is more accurate than the procedures recommended.

It may be necessary to determine the hydrologic effect of various activities on the rising and recession limbs of the hydrograph. If a hysteresis effect is prevalent, separate analyses may be made using the relationships established in step 3.

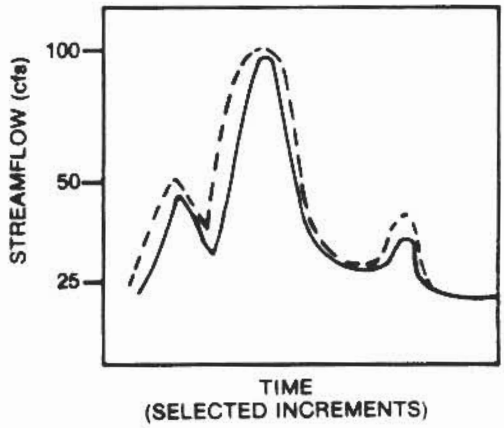

Figure VI.10a—Typical hydrograph.

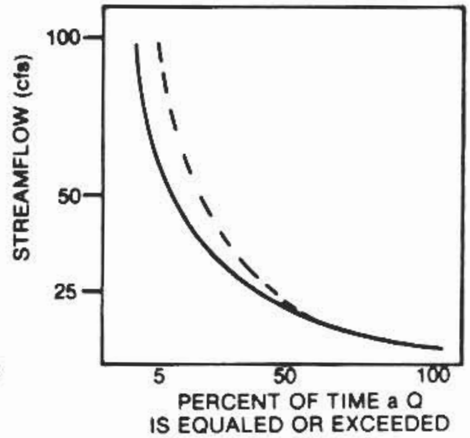

Figure VI.10b.—Flow duration curve.

Note: If silvicultural activity does not increase flow, the calculations involving post-activity flow related suspended and bedload increases would not be needed for the evaluation.

Suspended Sediment

Step 3. Establish Sediment Rating Curves and Determine Stream Channel Stability

Procedure: (a) Concurrently measure suspended sediment, and associated stream discharge over wide variations in flow conditions for a water year (fig. VI.11). After the data have been collected a regression analysis should be employed to calculate coefficient of determination and the log transformed regression equation of:

$$\log Y = b + n \log Q \qquad \text{(VI.1)}$$

where:

- log Y = logarithm of suspended sediment concentration (mg/l)
- b = constant representing intercept of the regression line
- n = constant representing slope of the regression line
- log Q = logarithm of stream discharge (cfs or m^3/sec)

The actual data points are plotted on log-log paper with suspended sediment in mg/l on the Y axis and stream discharge in cfs on the X axis. Using this data, coefficients for a regression equation of the form indicated in equation VI.1 are calculated. The regression line is then drawn on the figure (fig VI.12).

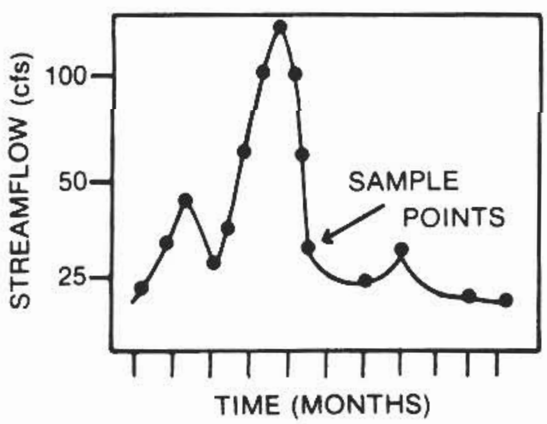

Figure VI.11.—Representative sediment sampling distribution.

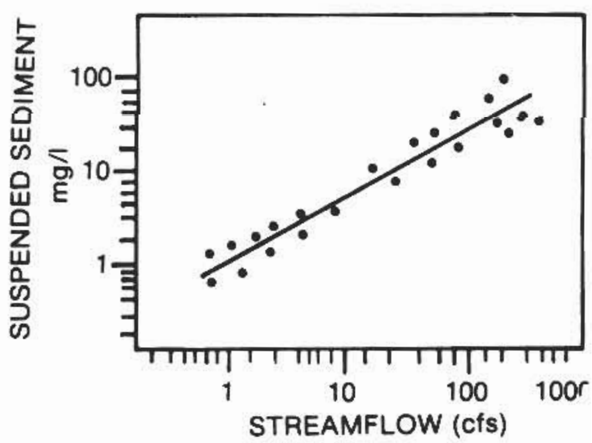

Figure VI.12.—Sediment rating curve.

(b) Calculate the coefficient of determination (r^2) for the relationship and identify variability (such as hysteresis effect).

(c) Determine stream channel stability rating for the reach being evaluated (Pfankuch 1975).

Discussion: Sampling should obtain sediment concentration for representative flows, as well as seasons where these concentrations expect to be varied. Sampling as a minimum for representative flow should reflect concentrations for the following conditions:

1. Early and/or low elevation snowmelt runoff;
2. Early versus late season stormflow runoff;
3. Rising stage for both stormflow and snowmelt runoff;
4. Recession stage for both stormflow and snowmelt runoff;
5. Bankful stage on higher peaks;
6. High elevation releases and/or snowmelt peaks;
7. Base flow;
8. Events which may affect the sediment rating curve, such as rain on snow events, short duration-high intensity storms, or long duration storms producing sustained high flows;
9. Disturbance factors influencing sediment supply, such as debris jams, changes in channel stability (sampled concurrently above and below to determine influence of stored sediment, etc.), road crossings or encroachments, and large areas of subdrainage hydrologically altered by vegetative modifications.

If significant differences in sediment concentration result from the rising versus falling limbs of the hydrograph or earlier storm peaks, these relationships should be kept separate and used in the calculation of both pre- and post-silvicultural activity streamflow effects to more accurately portray existing conditions. A more detailed hydrologic evaluation would increase the curve sensitivity for these conditions. Separate regression lines may be established and used for the appropriate flows when calculating pre- and post-silvicultural activity sediment discharge (steps 4 and 5) caused by increased flow only. This requires additional data on water yield to reflect the potential runoff response to a particular activity on various stormflow periods and rising versus falling limbs of the hydrograph (fig. VI.13) (Fredriksen 1977). The two sediment rating curves then can be applied to those respective portions of the post-silvicultural activity hydrograph (fig. VI.10a).

Step · 4. Calculate Pre-Silvicultural Activity Potential Suspended Sediment Discharge

Procedure: From the pre-silvicultural activity hydrograph (baseline + existing condition, fig. VI.10a) and the sediment rating curve (fig. VI.12), determine sediment concentration for each 7-day average flow condition. Worksheet VI.1 is provided for this calculation. The formula used in worksheet VI.1 is:

$$S_{pre} = (Q_{pre})\,(C)\,(K)\,(T) \qquad \text{(VI.2)}$$

where:

S_{pre} = **pre-silvicultural activity suspended sediment discharge (tons/yr)**

C = concentration of suspended sediment (mg/l)

Q_{pre} = pre-silvicultural activity streamflow (cfs or m^3/sec)

K = conversion factor 0.0027 (.0864 if streamflow is in m^3/sec) (Guy and Norman 1970)

T = duration (days)

Calculation format is provided in worksheet VI.1, columns 2 to 4. Summarized sediment discharge increments (col. 4, wksht. VI.1) is transferred to worksheet VI.3, item A. To obtain values of C, use the pre-silvicultural activity 6- or 7-day average flow (fig. VI.10a); then utilizing figure VI.12, sediment rating curve, read vertically to the regression line, then horizontally where the Y axis indicates corresponding values of suspended sediment concentrations (C). This is done for each flow value of pre-activity discharge given a specified (6- or 7-day) duration. Worksheet VI.1 provides an accounting format for these calculations.

Step 5. Calculate Post-Silvicultural Activity Potential Suspended Sediment Discharge

Procedure: From the post-activity hydrograph or post-activity flow duration curve (fig. VI.10 a or b) and the sediment rating curve (fig. VI.12), determine the sediment concentration for each 7-day average flow condition. Worksheet VI.1 is provided for this calculation. The formula that is used in worksheet VI.1 is the same as that in step 4, except that post-activity values for flow are used.

$$S_{post} = (Q_{post})\,(C)\,(K)\,(T) \qquad \text{(VI.3)}$$

where:

S_{post} = post-activity suspended sediment discharge due to flow increase

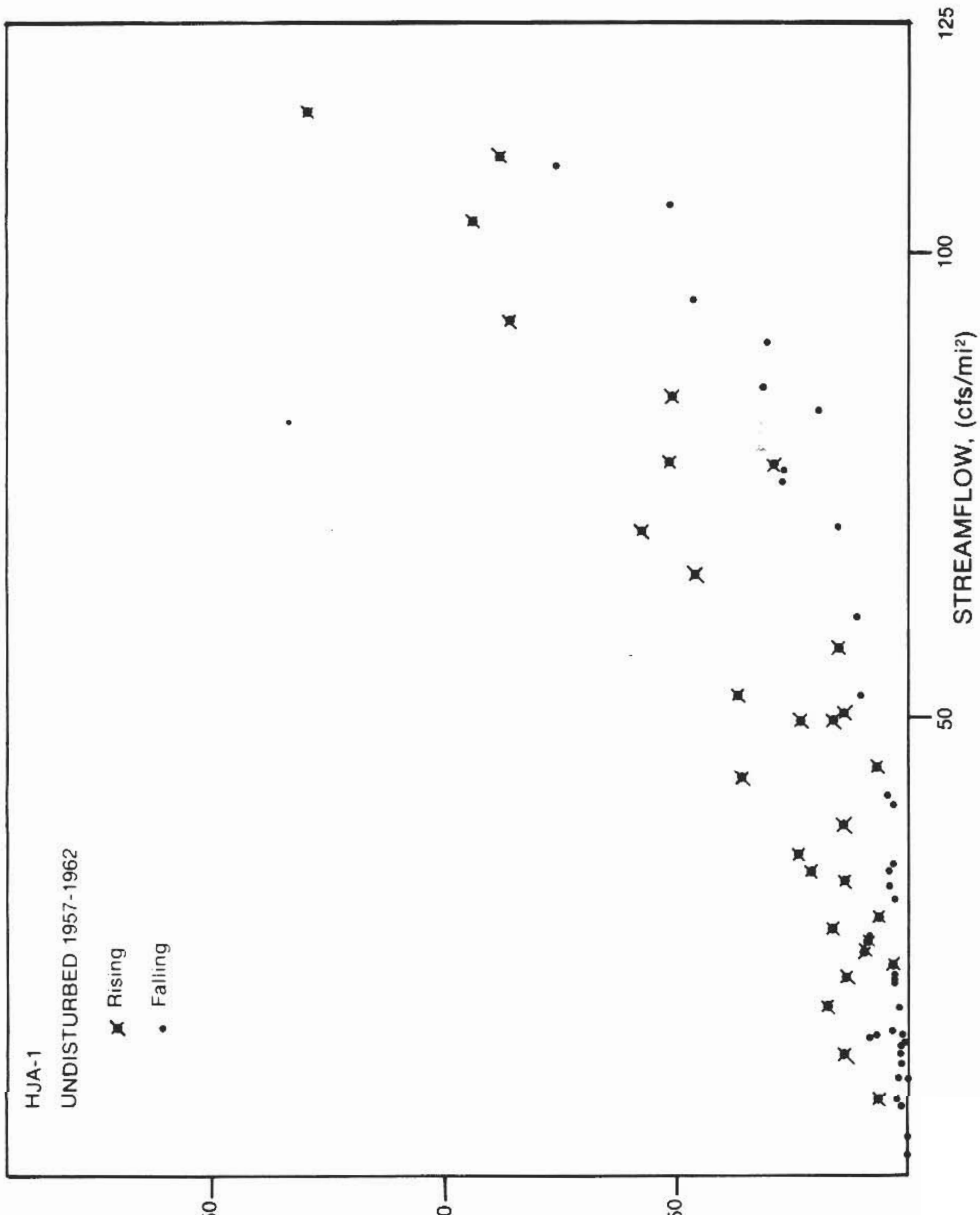

Figure VI.13—Sediment rating curve for H. J. Andrews Stream 1, showing variation in sediment concentration under rising versus falling limbs of the hydrograph. (Fredriksen 1977).

WORKSHEET VI.1

Suspended sediment quantification for ____________________

(1) Time increment			(2)	(3)	(4)	(5)	(6)	(7)	(8)	(9)
(a) With hydrographs use date; with flow duration curves use % of 365 days	(b) Number of days pre-silvicultural activity	(c) Number of days post-silvicultural activity	Pre-silvicultural activity flow (cfs)	Suspended sediment concentration (mg/l)	Total increment suspended sediment cols. (2) x (3) x (1.b) x .0027 (tons)	Post-silvicultural activity flow (cfs)	Suspended sediment concentration (mg/l)	Total increment post-silvicultural activity suspended sediment cols. (5) x (6) x (1.c) x .0027 (tons)	Maximum concentrations from selected water quality objective (mg/l)	Maximum sediment discharge cols. (2) x (8) x (1.b) x .0027 (tons)

(Totals are rounded to nearest tenth)

Total ________ tons/yr   Total ________ tons/yr   Total ________ tons/yr

Summary: Total pre-silvicultural activity suspended sediment discharge = ________
Total post-silvicultural activity suspended sediment discharge = ________
Total maximum sediment discharge = ________

Q_{post} = post-activity discharge (cfs)

C = concentration of suspended sediment (mg/l)

K = conversion factor 0.0027 (.0864 if streamflow is in m³/sec) (Guy and Norman 1970)

T = duration (days)

Summarize sediment discharge increments (col. 7, wksht. VI.1) and transfer total to worksheet VI.3, item B.

Discussion: The accuracy of this calculation is highly dependent on the hydrologic evaluation and on the observed variability in the sediment rating curves. A variability range may be presented as an option for tons/year of suspended sediment discharge. However, for comparative purposes, pre-activity values should be calculated similarly.

Step 6. Convert Suspended Sediment Limits in mg/l to tons/yr

Procedure: This calculation involves the same procedure used in step 4, except the suspended sediment concentrations (C_{MX}) are derived from various water quality objectives, expressed in mg/l. A conversion to comparable units in tons/year is needed to compare potentials for prescribed controls. Thus:

$$S_{MX} = (C_{MX})(Q_{pre})(T)(K) \qquad \text{(VI.4)}$$

where:

S_{MX} = maximum suspended sediment discharge (tons/yr)

C_{MX} = selected maximum suspended sediment concentrations (mg/l)

K = conversion factor 0.0027 (.0864 (metric tons) if streamflow is in m³/sec) (Guy and Normal 1970)

T = duration (days)

Discussion: The pre-silvicultural activity sediment rating curve is used to compare analysis output (tons/yr) to state standards which have allowable departures for suspended sediment concentration increases. Concentration values for the particular state standard are added to the existing concentrations for each 6- or 7-day flow increment (fig. VI.14).

If the water quality objective is to maintain equilibrium or stability of a stream system, a typical conversion would use stream channel stability ratings versus sediment rating curves. Exceedance levels may be inferred from the stability class lines using locally derived relationships (fig. VI.15). The major divisions above existing conditions of channel stability should be used. A conversion for pre-silvicultural activity flows from mg/l to tons provides an interpretation of the effects of introduced sediment (in tons) on channel stability.

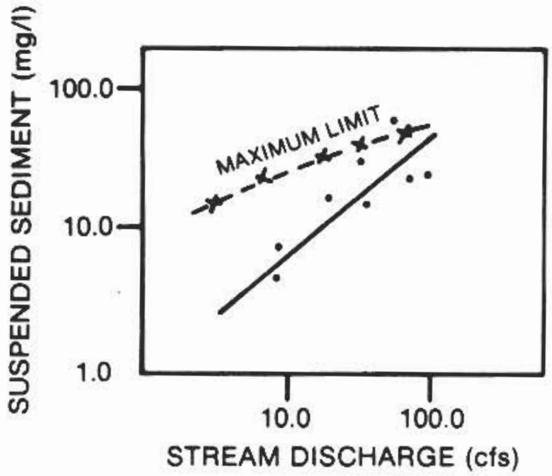

Figure VI.14—Use of a constant maximum limit for sediment concentration compared to sediment rating curve.

The calculation converts water quality objectives in mg/l to tons/year for comparative purposes only. It does not set objectives, but only provides a basis for comparison once water quality objectives are set: This allows comparison of suspended sediment discharge amount with these objections to determine when controls or mitigative measures may be applied. Columns 8 and 9 in worksheet VI.1 are provided for this analysis.

Bedload Calculation

Step 7. Establish Bedload Rating Curve

Procedure: Measure bedload transport (lb/sec or kg/sec) using the Helley-Smith bedload sampler concurrent with stream discharge (m³/sec or cfs) for representative flows.

The values of measured bedload transport in lb/sec or tons/day are evaluated against stream discharge in cfs in the log transformed regression equation:

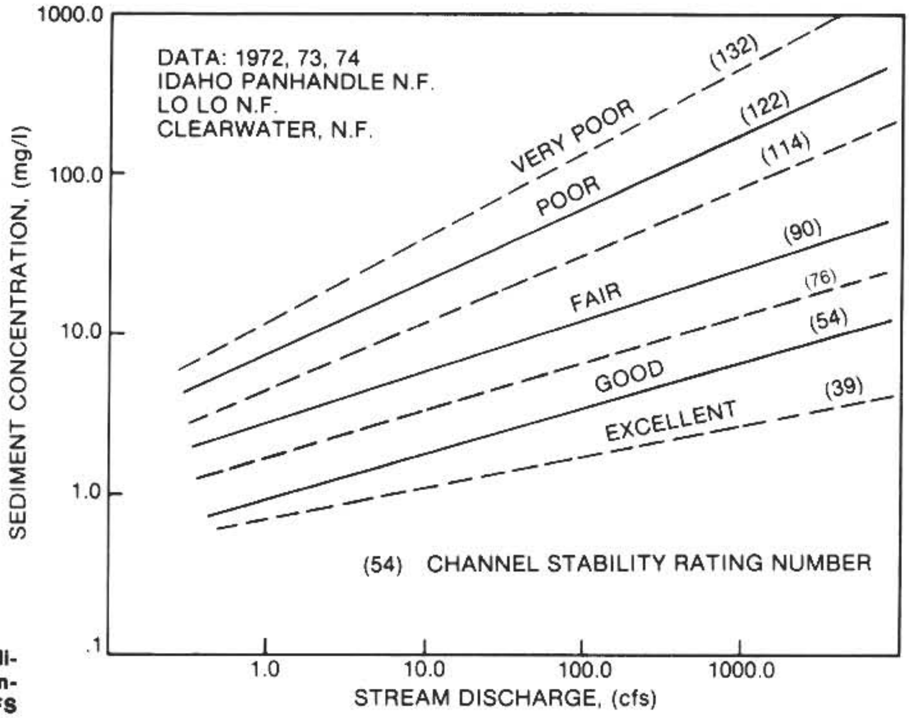

Figure VI.15.—Relationship of sediment rating curves to stream channel stability ratings, Region 1, USFS (Rosgen 1975b).

$$\log B_s = b + n \log Q \qquad \text{(VI.5)}$$

where:

$\log B_s$ = logarithm of bedload transport (lb/sec or tons/day)

b = constant representing intercept of the regression line

n = constant representing slope of the regression line

$\log Q$ = logarithm of stream discharge (cfs)

Regression analysis should be used to obtain the coefficient of determination (r^2) and the regression equation for the bedload rating curve.

Discussion: The same variables affecting the sampling design and representative flow monitoring apply to the bedload rating curves.

Step 8. Calculate Pre-Silvicultural Activity Potential Bedload Discharge

Procedure: Using bedload rating curve (step 7) and pre-activity excess water distribution (step 2) for 6- or 7-day time intervals, calculate annual bedload discharge using worksheet VI.2.

$$B_{pre} = (i_{b_{pre}})\,(T)\,(K) \qquad \text{(VI.6)}$$

where:

B_{pre} = pre-silvicultural activity bedload discharge (tons/year)

$i_{b_{pre}}$ = measured bedload transport rate (lb/sec) for pre-activity excess water

T = duration (days)

K = constant to convert lb/sec to tons/day

Discussion: The procedures used here are the same as in step 4, with the exception that bedload is used instead of suspended sediment. Enter the total of the pre-silvicultural activity potential bedload discharge as item E on worksheet VI.3.

Step 9. Calculate Total Pre-Silvicultural Activity Potential Sediment Discharge (Bedload and Suspended Load)

Add total pre-activity suspended sediment discharge (tons/year) (step 4) and total bedload sediment discharge (step 8), and enter on worksheet VI.3 as item K.

Step 10. Calculate Post-Silvicultural Activity Potential Bedload Discharge

Use worksheet VI.2, columns 1, 5, 6, and 7.

Procedure: Compute rates using post-silvicultural activity excess water (step 2) and bedload rating curves (step 7) using equation:

WORKSHEET VI.2

Bedload sediment quantification for ______________________

(1) Time increment			(2)	(3)	(4)	(5)	(6)	(7)
(a) with hydrographs use date; with flow duration curves use % of 365 days	(b) Number of days pre-silvicultural activity	(c) Number of days post-silvicultural activity	Pre-silvicultural activity flow Q_{pre} (cfs)	Bedload transport rate i_{bpre} (tons/day)	Total pre-silvicultural activity bedload discharge cols. (3) x (1.b) B_{pre}	Post-silvicultural activity flow Q_{post} (cfs)	Bedload transport rate i_{bpost} (tons/day)	Post-silvicultural activity bedload discharge cols. (6) x (1.c) B_{post}

(Totals are rounded to nearest tenth) Total ________ tons/yr Total ________ tons/yr

Summary: Total pre-silvicultural activity bedload discharge = ____________
Total post-silvicultural activity bedload discharge = ____________

WORKSHEET VI.3

Sediment prediction worksheet summary

Subdrainage name ______________________________ Date of analysis __________

Suspended Sediment Discharge

A. Pre-silvicultural activity total potential suspended sediment discharge (total col. (4), wksht. VI.1) (tons/yr) __________

B. Post-silvicultural activity total potential suspended sediment discharge (total col. (7), wksht. VI.1) (due to streamflow increases) (tons/yr) __________

C. Maximum allowable potential suspended sediment discharge (total col. (9), wksht. VI.1) (tons/yr) __________

D. Potential introduced sediment sources: (delivered)

1. Surface erosion (tons/yr) __________
2. Soil mass movement (coarse) (tons/yr) __________
3. Median particle size (mm) __________
4. Soil mass movement-- washload (silts and clays) (tons/yr) __________

Bedload Discharge (Due to increased streamflow)

E. Pre-silvicultural activity potential bedload discharge (tons/yr) __________

F. Post-silvicultural activity potential bedload discharge (due to increased streamflow) (tons/yr) __________

Total Sediment and Stream Channel Changes

G. Sum of post-silvicultural activity suspended sediment + bedload discharge (other than introduced sources) (tons/yr) __________ (sum B + F)

H. Sum of total introduced sediment (D) = (D.1 + D.2 + D.4) (tons/yr) __________

I. Total increases in potential suspended sediment discharge

1. (B + D.1 + D.4) - (A) (tons/yr) __________
2. Comparison to selected suspended sediment limits (I.1) - (C) (tons/yr) ± __________

J. Changes in sediment transport and/or channel change potential (from introduced sources and direct channel impacts)

1. Total post-silvicultural activity soil mass movement sources (coarse size only) (tons/yr) ________

2. Total post-silvicultural soil mass movement sources (fine or washload only) (tons/yr) ________

3. Particle size (median size of coarse portion) (mm) ________

4. Post-silvicultural activity bedload transport (F) (tons/yr) ________

Potential for change (check appropriate blank below)

Stream deposition ____

Stream scour ____

No change ____

K. Total pre-silvicultural activity potential sediment discharge (bedload + suspended load) (tons/yr)

________ (sum A + E)

L. Total post-silvicultural activity potential sediment discharge (all sources + bedload and suspended load) (tons/yr)

________ (sum G + H)

M. Potential increase in total sediment discharge due to proposed activity (tons/yr)

________ (subtract L - K)

$$B_{post} = (i_{b_{post}}) (T) (K) \qquad (VI.7)$$

where:

B_{post} = post-silvicultural activity bedload discharge (tons/year)

$i_{b_{post}}$ = bedload transport rate (lb/sec) for post-activity excess water

T = duration (days)

K = constant to convert lb/sec to tons/day

Discussion: The increase in bedload sediment discharge is a function of increased streamflow through vegetative alterations.

Total Sediment

Step 11. Obtain Introduced Sediment from Soil Mass Movement

Obtain total potential sediment delivered by soil mass movement processes in tons/year (ch. V). Add to total sediment discharge, all sources, step 16. Record on worksheet VI.3, lines D.2 and D.4.

Step 12. Obtain Total Coarse-Size Sediment from Soil Mass Movement

Obtain total potential introduced coarse-sized sediment delivered by soil mass movement processes. Record on worksheet VI.3, lines D.2 and J.1.

Procedure: Subtract the percentage of fines (silts and clays) from total delivered sediment to obtain the coarse fragment size (sands and larger) (Data input for step 20).

Discussion: This indicates only the potential of increased sediment available to a stream. Since sediment routing is not attempted with these procedures, it is not possible to determine the amount of coarse-sized soil mass movement material that would be available to the third order drainageway over various periods. A certain amount will go into temporary storage. A qualitative evaluation in step 21 may provide additional interpretations on stream channel impacts due to the change in sediment supply from this source.

Step 13. Determine Fine Size Volume from Soil Mass Movement

Procedure: Calculate percent by volume of soil mass movement material that is composed of the fine soil fraction, .0625 mm or smaller — silts and clays (washload). Compare output at step 16 — post-activity total suspended sediment discharge at the third order stream reach (step 15).

Step 14. Obtain Total Introduced Suspended Sediment (tons/yr) from Surface Erosion, Chapter IV

Procedure: Self-explanatory.

Discussion: Since the assumption is made that the delivered sediment from surface erosion is washload (silts and clays), then the total volume delivered would be evaluated at the third order reach. These data are used to compare introduced sediment to selected limits (step 15).

Step 15. Compare Post-Silvicultural Activity Total Potential Suspended Sediment (in Tons) to Selected Limits

Procedure: Add total of suspended sediment increases from:

1. Flow related increases (step 5)
2. Surface erosion source (step 14)
3. Soil mass movement, washload (step 13).

Subtract total of post-activity tons from allowable maximum sediment discharge (S_{MX}).

Discussion: Individual processes (surface erosion, soil mass movement, and streamflow) can be analyzed independent of each other to determine respective contributions. In this manner, controls which relate to specific processes may be properly recommended where applicable (tables II.2 to 14, ch. II).

Step 16. Post-Silvicultural Activity Total Potential Sediment Discharge—All Sources

Procedure: Total Sediment = Σ [output steps (5) (10) (11) and (14)] Add total of sediment discharge (in tons/yr) from:

1. Suspended sediment post-activity flow related increases (step 5)
2. Bedload post-activity flow related increases (step 10)
3. Soil mass movement volumes (step 11)
4. Surface erosion source (step 14).

Discussion: This calculation only evaluates potential changes in sediment availability within a third order watershed. It does not assume that all eroded material is routed to the third order reach.

Step 17. Increase in Total Potential Sediment Discharge From Silvicultural Activities

Procedure: Subtract total volume (tons/year) of pre-activity sediment discharge (step 9) from total post-activity sediment discharge (step 16).

Discussion: Although the data output represents a combined total of all sources, individual contributions may be evaluated where needed when considering management controls or mitigative measures.

Step 18. Collect Channel Geometry Data for Third Order Stream

Procedure: Measure surface water slope (ft/ft) on the stream reach where bedload data is collected. Also measure stream width for the various flows as measured in the establishment of the bedload rating curve.

Discussion: This information is necessary to establish a sediment transport rate-stream power relationship (step 20) for the third order watershed. It is also required to obtain changes in sediment transport rate on first to third order stream channels caused by activities which affect either surface water slope or bankful stream width (step 19).

Step 19. Evaluate Post-Silvicultural Activity Channel Impacts

Procedure: Determine post-activity changes influencing stream power calculations by surface water slope or bankful stream width. Using post-activity bankful width and/or surface water slope, revised stream power calculations and resultant revised bedload transport rates for impacted stream reaches (step 20) may be obtained.

Discussion: Changes in stream width and/or surface water slope can be obtained by field determinations based on the results of similar activities on stream reaches (i.e., upstream versus downstream measured surface water slope associated with debris jams indicates relative change anticipated with similar activities).

Step 20. Establish Bedload Sediment Transport Rate-Stream Power Relationship for Third Order Stream Reach

Procedure: Using width (step 2), water surface slope and actual *bedload transport data (step* 7), establish the relationship:

$$\log i_b = a + b \log_\omega \qquad \text{(VI.8)}$$

where:

$\log i_b$ = logarithm of measured bedload transport rate (lb/sec/ft)

a = intercept of regression line

b =slope representing regression line

$\log_\omega$ = logarithm stream power (lb/sec/ft)

stream power = [62.4 lbs ft^3 × surface water slope (ft/ft) × stream discharge (cfs)] ÷ stream width

Use worksheet VI.4 for this calculation.

Determine the median sediment size in transport from seiving the bedload sampler catch (D_{50}). If the sizes in transport vary as stream power increases, analyze data separately to develop various particle size stream power requirements as shown in figure VI.8 (Leopold and Emmett 1976).

Discussion: The purpose of this calculation is to develop a local relationship of bedload transport rate-stream power to predict potential stream channel adjustments. If it is desired to complete the same analysis on first and second order streams, it will be necessary to obtain site specific information for the respective reaches. This is required because a flow evaluation is not provided for the first and second order streams.

The data required are:

1. Measure surface water slope (from riffle to riffle).
2. Measure bankful stage width (using bankful stage as described by Williams (1977)).
3. Measure bankful stage depth.

The reliability of the data will be reduced by extrapolating bedload transport rate data to the first and second order streams. Extrapolation is less reliable because actual changes in bedload particle size in transport and corresponding stream powers are not measured. The processes affecting transport rate, however, are the same; therefore, the reduced reliability may be acceptable. If it is not acceptable, measurement of the first and second order reaches is recommended to more accurately develop the bedload transport rate-stream power relationships.

Step 21. Qualitative Determinations of Channel Change Potential Based on Introduced Sediment from Soil Mass Movement and Channel Impacts (wksht. VI.5)

Procedure:

a. Determine change in surface water slope.
b. Determine change in bankful stream width.
c. Determine change in bankful stream depth.
d. Obtain volume of introduced sediment from soil mass movement source (step 12).

WORKSHEET VI.4

Bedload transport-stream power relationship for ____________________

(1) Water surface slope S (ft/ft)	(2) Constant (62.4) K (lb/ft^3)	(3) Measured stream discharge Q (cfs)	(4) Stream width W (ft)	(5) Stream power $\frac{\text{cols. (1)} \times \text{(2)} \times \text{(3)}}{\text{col. (4)}}$ (ft/lb/sec)	(6) Measured bedload transport rate i_b (tons/day)	(7) Convert bedload transport from tons/day to ft/lb/sec, [col. (6) x 2,000] ÷86,400 x col.(4) i_b (ft/lb/sec)

Complete the following analysis:

a. Plot value of stream power (ω), column (5) on X-axis and values of bedload transport rate [i_b, column (7)], on double log graph paper.

b. Calculate regression equation and coefficient of determination (r^2).

WORKSHEET VI.5

Computations for step 21 ______________________
(stream name)

Changes in bedload transport-stream power due to channel impacts

1. Potential changes in channel dimensions

a. Bankful stage width (W_{pre}) ______ (W_{post}) ______

b. Bankful stage depth (D_{pre}) ______ (D_{post}) ______

c. Water surface slope (S_{pre}) ______ (S_{post}) ______

d. Bankful discharge (Q_{Bpre}) ______ (Q_{Bpost}) ______

where: $Q_{Bpre} = 0.366 + 1.33 \log A_{pre} + 0.05 \log S_{pre} - 0.056 (\log S_{pre})^2$

where: A = cross-sectional area (a) x (b) ______

S = water surface slope (c) ______

Calculate Q_{Bpost} using post-silvicultural A and S

$$Q_{Bpost} = 0.366 + 1.33 \log A_{post} + 0.05 \log S_{post} - 0.056 (\log S_{post})^2$$

2.a. Pre-silvicultural activity stream power calculation (ω_{pre})

$$\omega_{pre} = \frac{\underset{(1.c)}{S_{pre}} \times \underset{(K)}{62.4} \times \underset{(1.d)}{Q_{Bpre}}}{\underset{(1.a)}{W_{pre}}} = \_\_\_\_\_\_$$

2.b. Post-silvicultural activity stream power calculation (ω_{post})

$$\omega_{post} = \frac{\underset{(1.c)}{S_{post}} \times \underset{(K)}{62.4} \times \underset{(1.d)}{Q_{Bpost}}}{\underset{(1.a)}{W_{post}}} = \_\_\_\_\_\_$$

3. Calculate post-silvicultural activity bedload transport rate at bankful discharge, using post-silvicultural activity stream power

e. Determine median particle size (mm) of delivered soil mass movement material.

f. Calculate bankful discharge on impacted stream reach.

Procedure for determining bankful discharge:

(1) Determine upper limits of the active floodplain (Williams 1977).

(2) Measure bankful stream width.

(3) Measure bankful stream depth.

(4) Calculate area (width × depth).

(5) Measure water surface slope.

(6) Solve for bankful discharge, Q in equation.

$$\log Q = 0.366 + 1.33 \log A + 0.005 \log S - 0.056 (\log S)^2 \quad \text{(VI.9)}$$

(Riggs 1976)

where:

Q = discharge (cfs)

A = area (ft^2)

S = water surface slope (dimensionless)

g. Extrapolate bedload transport rate-stream power relationships established on third order reach to the reach being evaluated.

h. Calculate maximum bedload transport rate using bankful discharge stream power. Compare to total introduced sediment from soil mass movement source. If introduced sediment exceeds transport rate at bankful discharge, sediment deposition may be expected in the stream reach.

i. Calculate changes in sediment transport rate caused by a reduction in surface water slope from debris jams. If revised stream power calculation creates a reduction in sediment transport rate, sediment deposition in the channel may be expected. This assumes there is no reduction in sediment availability within the watershed upstream of the reach being evaluated.

Discussion: These qualitative evaluations indicate relative potential for channel change, namely deposition or stream channel aggradation (longer than 1 year of influence). A numerical indicator is used for this potential change. Long-term monitoring is necessary to provide quantitative prediction and time series recovery of stream channels in the interim. These calculations are recommended when considering management controls and/or mitigative measures.

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APPENDIX VI.A

EXAMPLES OF CHANNEL STABILITY RATINGS

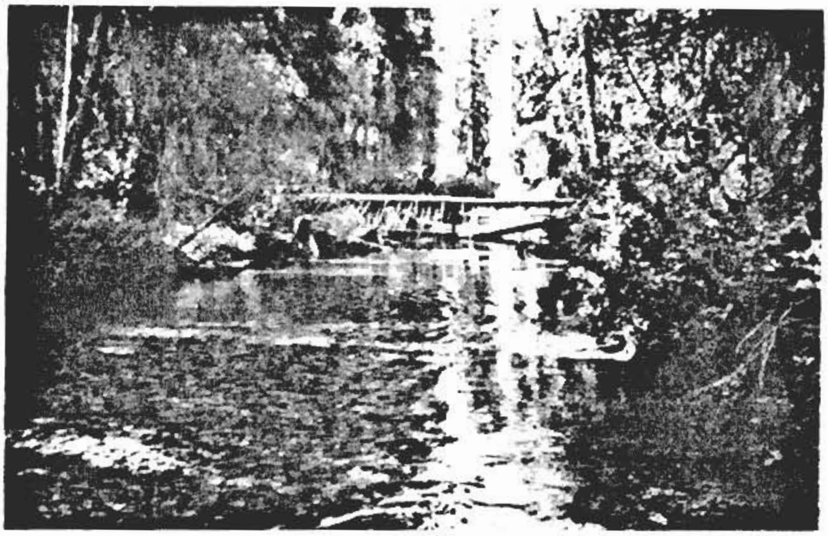


Figure VI.A.1.—Stream channels indicative of a stable channel due to resistant bed and bank materials.

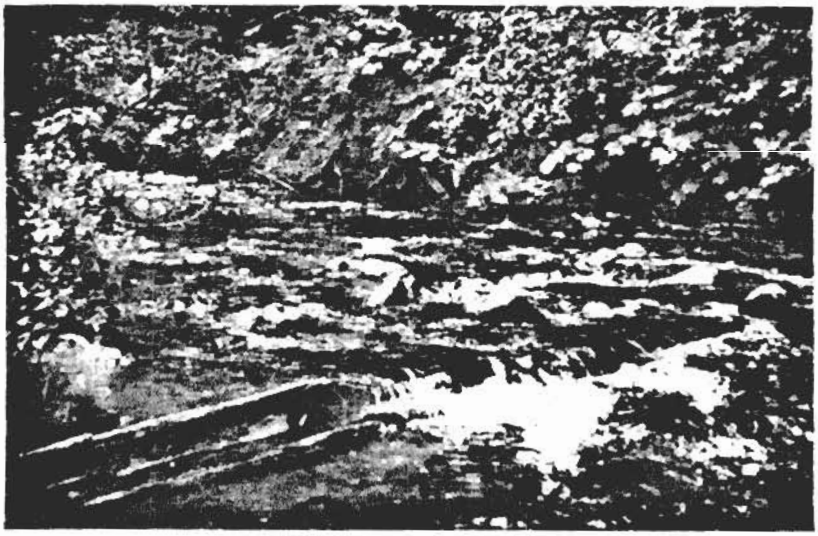
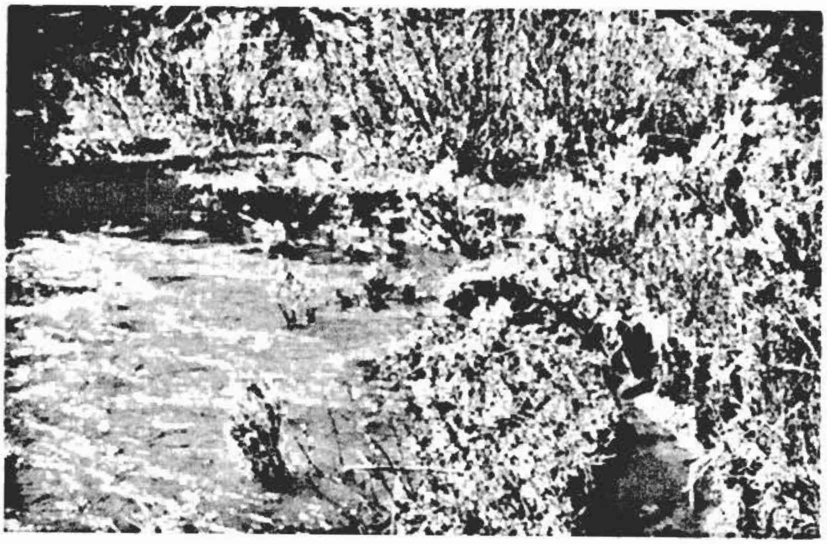


Figure VI.A.2.—Stream channels indicative of a stable channel due to resistant bed and bank materials.

Figures VI.A.3. - VI.A.5.—Stream channels indicative of stable channel due to resistant bed and bank materials.



Figures VI.A.6. - VI.A.8.—Highly unstable channels or channels having poor stability ratings are generally associated with easily detached bank and bed material where channel erosion is significant.

Figure VI.A.9.—Stability and associated sediment supply affected by organic debris which increase sediment storage with resultant channel changes and bank erosion.

Figure VI.A.10.—Stability and associated sediment supply affected by organic debris. Excessive deposition and associated increased sediment storage occurs with resultant channel changes, bank erosion and other changes.

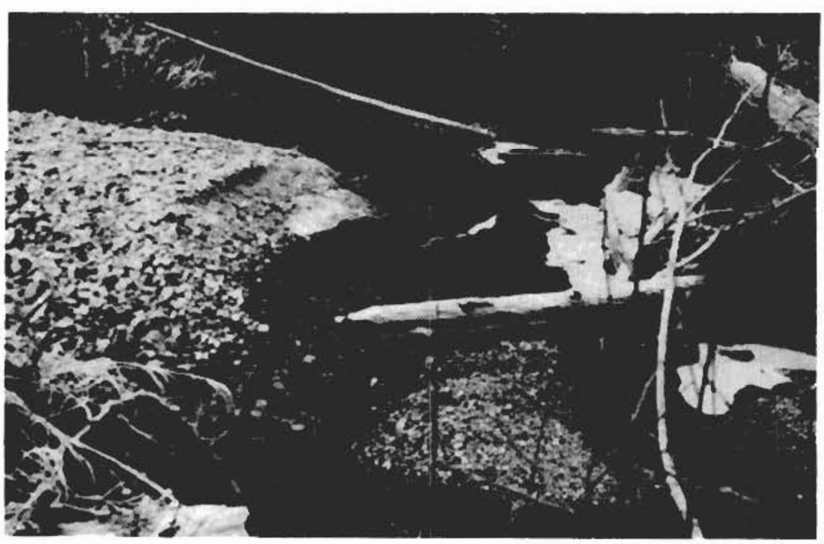


Figure VI.A.11.—Changes in stability due to increases in sediment supply from road crossings. Such introduced sediment sources can exceed the carrying capacity of the stream.

Figure VI.A.12.—Soil mass movement, due to debris avalanche processes, deliver excessive amounts of sediment to the stream. This will often change the stream stability and associated supply-energy relationship.

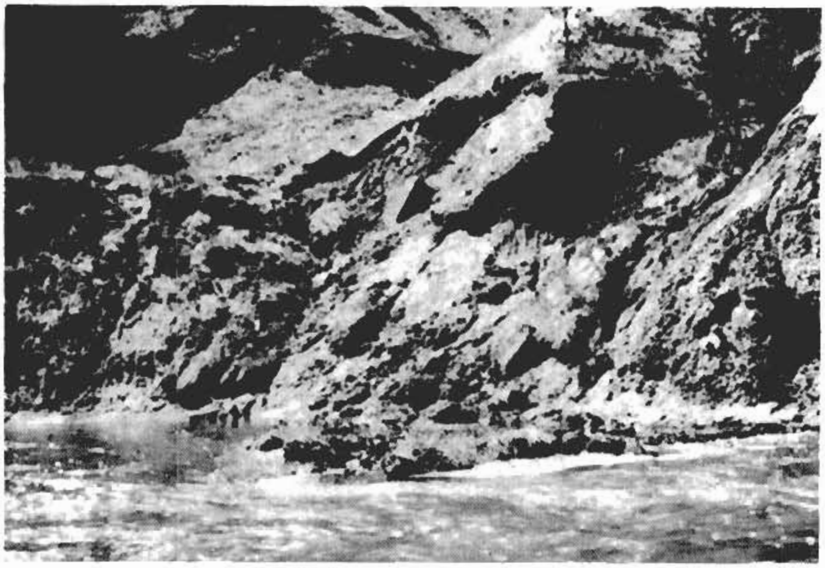


Figure VI.A.13.—Soil mass movement, due to slump-earthflow processes, deliver excessive amounts of sediment to the stream. This will often change the stream stability and associated supply-energy relationships.

APPENDIX VI.B

RELATIONSHIPS BETWEEN SEDIMENT RATING CURVES AND CHANNEL STABILITY

To provide a link between the morphological characteristics of stream channels, as determined by the channel stability rating procedure (Pfankuch 1975), and sediment rating curves, regression analyses were made on over 80 streams in northern and central Idaho and northwestern Montana involving sediment rating curves and channel stability ratings. The relationship is shown in figure VI.B.1 (Rosgen 1975b). Correlation coefficients (R^2) were 0.94 for the "good and excellent" (38 to 76), 0.91 for the "fair channel stability" (77 to 114), and 0.94 for the "poor or unstable" channels (115 to 132). A covariance analysis was conducted (Bernath 1977) indicating highly significant correlations when comparing stability ratings for various populations. The F values were highly significant at the 0.01 level.

Since then, work conducted in California has shown widespread application of this technique where 27 streams with sediment rating curves were evaluated using the same stability procedures (fig. VI.B.2). Concentrations for the same flows are considerably higher in the California streams, but the stability evaluation provides a comparison of the different regression constants and stability ratings within a given locale using the same procedures (Laven 1977). Similar relationships are indicated in figure VI.B.3 where sediment rating curves were related to stability ratings in Colorado (Rosgen 1977b).

Additional validation of this procedure has been conducted in Wyoming, Oregon, New Mexico, North Carolina, New Hampshire, Vermont, and Virginia; tentative results indicate that this procedure applies to many areas other than where it was developed (Rosgen 1977a). This success is due to the application of the procedures (process related) rather than extrapolation of actual curves or regression equations from region to region. The use of this procedure demands the development of

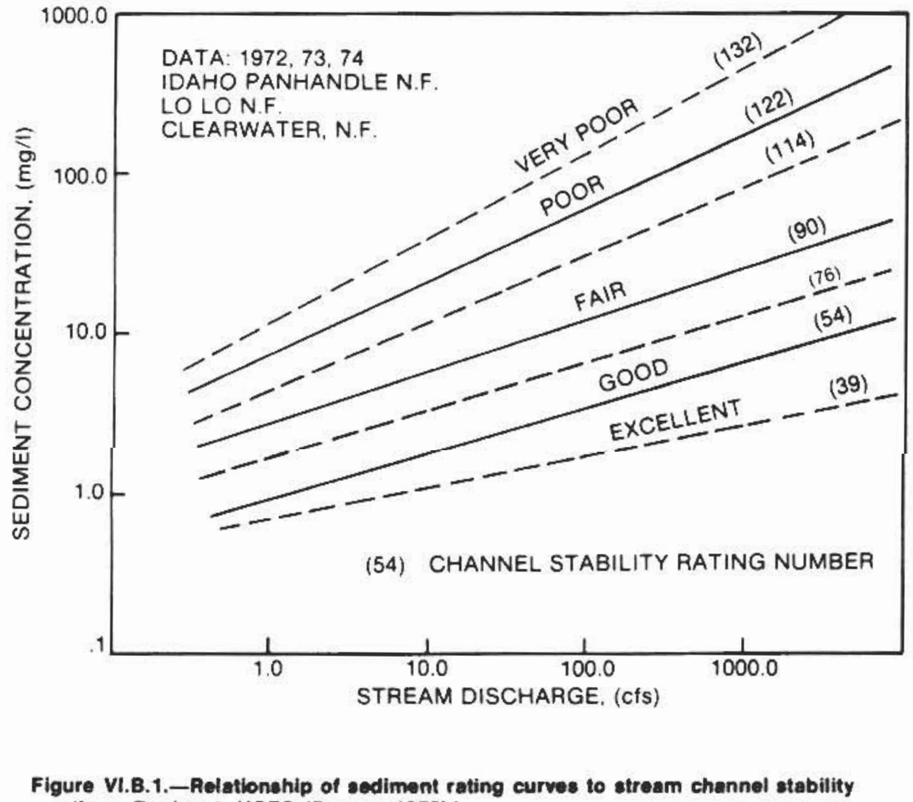


Figure VI.B.1.—Relationship of sediment rating curves to stream channel stability ratings, Region 1, USFS (Rosgen 1975b).

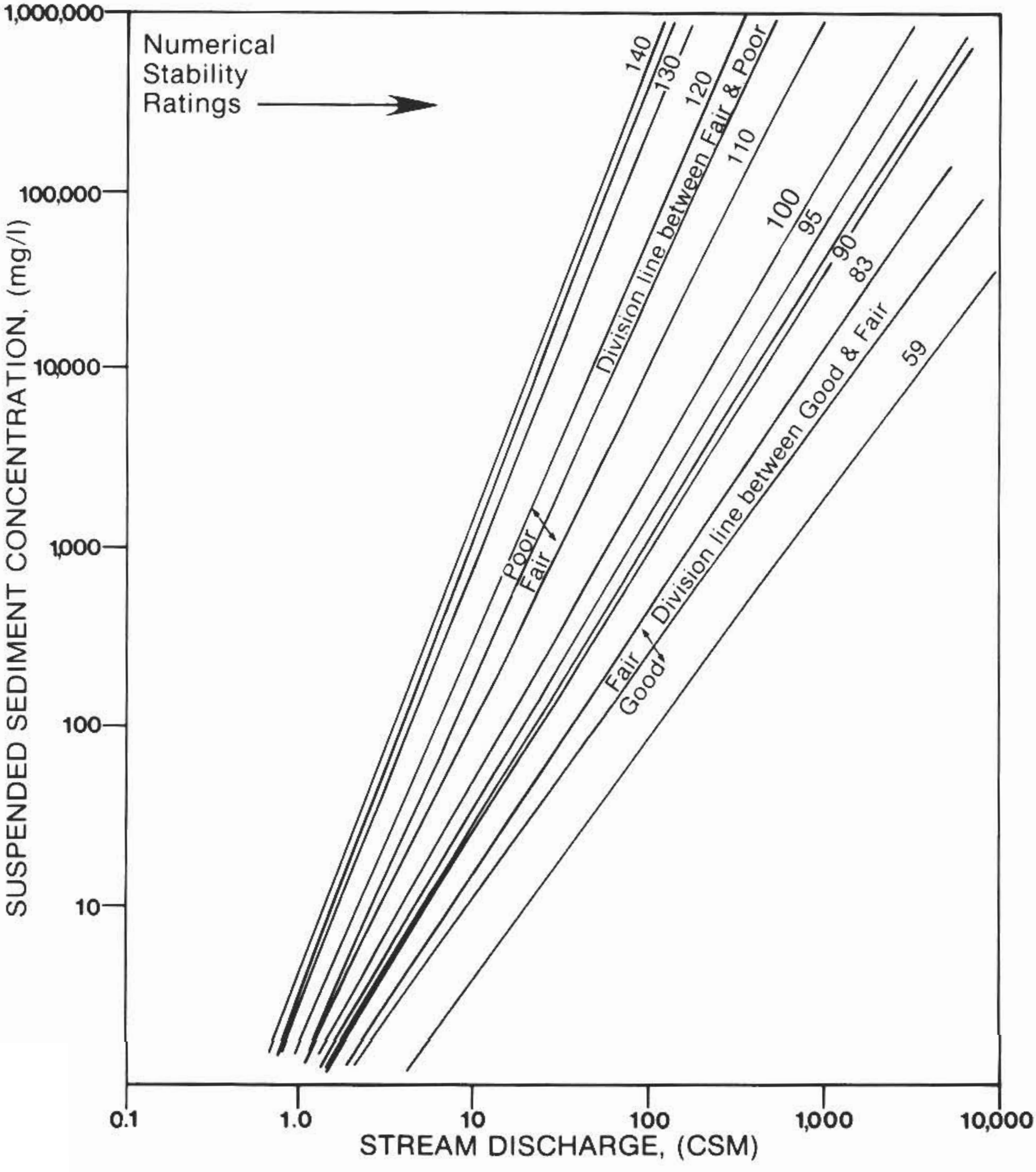


Figure VI.B.2.—Relationship of channel stability ratings to sediment rating curves in the Redwood Creek drainage, California (Laven 1977).

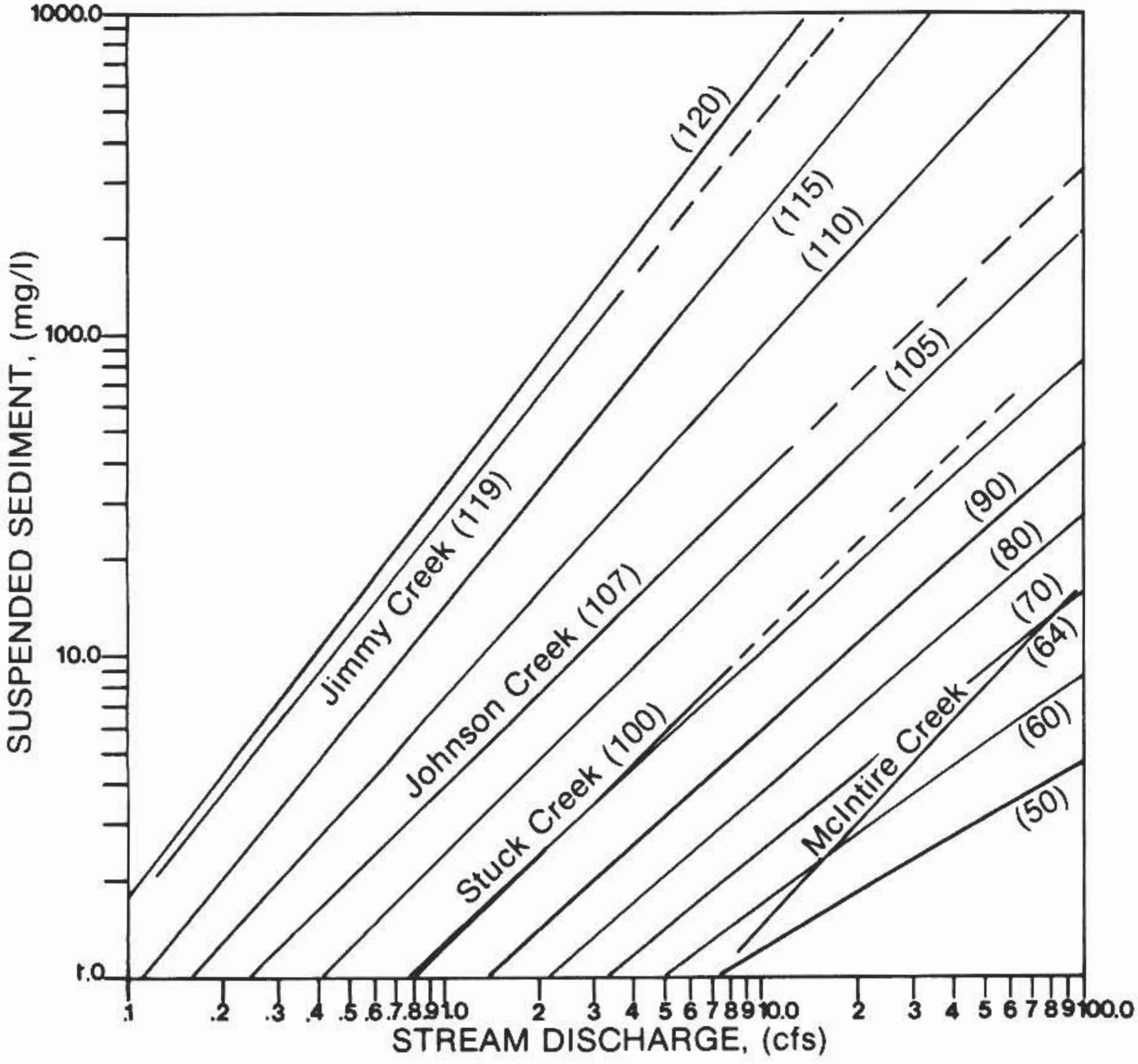


Figure VI.B.3.—Relationship of channel stability ratings to sediment rating curves for streams in the central Rocky Mountain region. (Rosgen 1977a).

APPENDIX VI.C

TIME SERIES ANALYSIS-RECOVERY PROCEDURE

It is often desirable to determine the duration of sediment impacts in a stream system. Little work is available which sets time series recovery for sediment rating curves, although observations indicate relative rates of recovery which vary considerably between streams. It is not possible to predict this recovery at this time; however, a procedure can be applied once channel morphological data are collected and pre- and post-sediment rating curves are measured.

Time recovery for streams using the sediment rating curve approach may be shown as:

A. Pre-silvicultural activity sediment rating curve or baseline characterization relationship.

$$\log Y = b + n \log Q \qquad \text{(VI.1)}$$

where:

- $\log Y$ = logarithm of pre-silvicultural activity suspended sediment concentration (mg/l)
- b = pre-silvicultural activity regression constant expressing intercept of the regression line
- $\log Q$ = logarithm of pre-silvicultural activity instantaneous stream discharge in cubic feet per second
- n = pre-silvicultural activity regression exponent expressing slope of the regression line

B. Post-silvicultural activity relationship expressing the time series recovery.

$$Y_t^* = (b^* e^{-Yt})\,(Q)^{(n^* e^{-zt})} \qquad \text{(VI.C.1)}$$

where:

- Y_t^* = post-silvicultural activity sediment concentration (mg/l) for a specified time following activity
- b = post-silvicultural activity regression constant expressing intercept of the regression line
- e = base of natural logarithms
- $-Y$ = negative exponent expressing relationship of recovery of intercept
- Q = post-silvicultural activity instantaneous stream discharge (ft^3 per section)
- n^* = post-silvicultural activity regression exponent expressing slope of the regression line
- $-z$ = negative exponent expressing recovery relationship of slope
- t = time (years) since initial disturbance

The relationships can be used to determine the rate of decline of the sediment rating curve following disturbance. Data requirements include the availability of measured pre- and post-silvicultural activity rating curves on streams to calculated values of Y^t and zt for similar stream systems for various years.

Models which determine potential "time-trends" in erosion and sedimentation are published and have been used in the central and northern Rocky Mountains (Megahan 1974 and Leaf 1974). Sediment reduction resulting from roads was primarily addressed where vegetative recovery greatly reduced delivery to a stream.

Before this stream channel-time recovery approach can be applied, stream morphological data will be needed prior to and following treatments of various streams to determine what variables are responsible for the shift in the sediment rating curve. Before adjusted values of Y^t and zt are available, qualitative broad interpretations of recovery are presently all that can be applied.

local curves based on actual sediment rating curve data. Once this step has been completed, information can be obtained from many miles of stream reach upstream or adjacent to where sediment data have been collected. Thus, the channel stability procedure, if used in a consistent comparative analysis over a wide range of stream types, can be used to infer the regression constants of the sediment rating curves. This would not be as accurate as actual measurements on 100 percent of the stream reaches being evaluated in a subdrainage; however, time and financial constraints might justify this approach once local validation has been accomplished. Potential shifts in stability as a result of direct sediment introduction may be inferred through the use of channel stability — sediment rating curve relationships in a given locale.

The "stability threshold" of streams can be interpreted as the lines between the major stability classes as shown in figure VI.B.1. This interpretation would be used where either actual or proposed potential sediment discharge, as calculated, could be compared to that sediment discharge using the maximum concentrations for the stability class and pre-activity seasonal distribution of excess water. These are based on measured data in the development of these relationships. If potential introduced sediment is anticipated during periods of lower flow, a comparison may be made, utilizing less than bankful stage discharge. If the increased supply is higher than the maximum sediment discharge for that flow condition, a stability change or associated shift in sediment rating curve may occur.