U.S. Department of Agriculture
SOIL CONSERVATION SERVICE
Engineering Division

GEOLOGY NOTE NO. 2

PREDICTION OF THE CONCENTRATION OF FINE SEDIMENT IN CHANNELS FROM SINGLE STORM EVENTS

April 1980

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<u>Contents</u> Page

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Summary

Channel design using the allowable velocity approach in SCS Technical Release 25 requires a knowledge of the sediment concentration in the water. This procedure provides a method of estimating the concentration by combining the fine sediment from uplands with the fine portion of sediment from channels. Base flow and the sediment concentration in it are also included if significant. The procedure in this note to predict the yield of fine sediment resulting from erosion during a single storm is for use on an interim basis when considered applicable and measured data are not available.

Introduction

Procedures in Technical Release 25, "Design of Open Channels," require a knowledge of the sediment concentration of the water carried by the channel. Other things being equal, 1) channels which carry water with high fine sediment concentrations can withstand higher velocity flows than those channels that carry water with low concentrations and, 2) the larger the storm the greater the erosion. Technical Release 25 defines fine sediment as those sizes smaller than 0.074 mm, sediment-laden as discharges having more than 20,000 ppm of fine sediment, and sediment free as having less than 1,000 ppm. Channel design is usually based on the runoff from either the one and/or ten percent chance of occurrence storm; therefore, sediment concentration should be estimated for whichever event is selected.

The Modified Universal Soil Loss Equation (MUSLE) (Williams) is used to predict sediment yield from sheet and rill erosion and the portion of the sediment yield finer than 0.074 mm is estimated. The soil loss factors should be selected for the time of the year in which the design storm is expected to occur. The sediment yield of material finer than 0.074 mm from channel-type erosion is then estimated. The sum of these yields represents the total amount of fines reaching the point of concern. The volume of runoff is then converted to weight. If base flow and the sediment concentration in it are significant, the values for these parameters are added to the weight of the water and sediment in the appropriate formula. The approximate average and peak concentrations of fines can then be calculated.

Suspended Sediment Concentrations

The sediment concentration is not fixed throughout the hydrograph. It is affected by many factors, and the range of variation during one storm period may differ from those of other storm periods. Availability of sediment is a major factor affecting sediment concentration whether

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sediment in the channel flow results from erosion in the uplands or sediment stored in channels. Basin size may also affect the relationship between sediment concentration and water discharge and the shape of the concentration graph. Usually the smaller drainage area or the watershed with major sediment sources located near the main channels will show a closer correlation of the peak of sediment concentration with peak of water discharge. The time of peak concentration of sediment with respect to time of peak water discharge becomes significant when it is necessary to classify the flow as sediment-laden or sediment-free. For purposes of this procedure it is assumed the water and sediment discharges peak simultaneously.

The average concentration of fine sediment in the flow in the design channel can be calculated with the following equation:

$$\bar{C} = \left(\frac{S}{S + W}\right) \times 10^6$$

where $\bar{C}$ = average concentration of fine sediment in the flow
S = weight of fine sediment in total discharge
W = weight of water in total discharge

It is desirable to estimate the peak concentration of fines in the flow. The water and sediment discharge curves for nine events from four areas were studied and a relationship between average sediment concentration and peak sediment concentration was derived. The instantaneous peak sediment concentration ranged between 1.69 and 2.67 of the average sediment concentration. The higher values appeared to be related to the larger storms. For this procedure the factor of 2.5 will be used in estimating peak sediment concentration.

The following equation can be used to estimate the instantaneous peak fine sediment concentration:

$$C_p = 2.5 \left(\frac{S}{S + W}\right) \times 10^6$$

where C_p = peak concentration of fine sediment in the flow
S = weight of fine sediment in total discharge
W = weight of water in total discharge

If base flow exists and the sediment concentration is significant the values for these parameters are added to the weight of water (W) and sediment (S) in the above formulas.

Sampling

Representative upland soil samples (from all sediment sources) are needed to estimate that portion of the sediment yield smaller than 0.074 mm. Samples of the material subject to sheet and rill erosion should come from the top few inches of the soil, while samples from gully and stream channels should be collected from the banks and bed.

Sediment Yield Prediction

This procedure estimates the amount of fines in the sediment yield from sheet, rill, and channel-type erosion. The total sediment yield from sheet and rill erosion is estimated by use of the MUSLE. Then the portion finer than 0.074 mm is estimated. The total sediment from channel-type erosion and the portion finer than 0.074 mm are estimated. Finally, the sediment yield of material finer than 0.074 mm from sheet and rill erosion is added to that from channel erosion.

The Universal Soil Loss Equation (USLE) times a sediment delivery ratio is a sediment yield equation. The MUSLE replaces the R factor of the USLE and the sediment delivery ratio with a runoff energy factor to predict sediment yield. This runoff energy factor is the volume of runoff times the peak runoff for a storm. The MUSLE is as follows:

$$S = 95 \ (Q \times q_p)^{0.56} \times K \times LS \times C \times P$$

where S = sediment yield from an individual storm in tons from sheet and rill erosion only,

Q = volume of runoff in acre-feet,

q_p = peak flow rate in cubic feet per second,

K = the soil-erodibility factor,

LS = the slope length and gradient factor,

C = the crop management factor, and

P = the erosion control practice factor.

The values for the volume of runoff in acre-feet (Q) and the peak flow rate in cubic feet per second (q_p) can be obtained from the hydrologist who may use SCS TR 20, TR 55, or the Engineering Field Manual.

The metric equivalent for MUSLE is:

$$S = 11.8 \ (Q \times q_p)^{0.56} \times K \times LS \times C \times P$$

where S = sediment yield from an individual storm in metric tons,

Q = storm runoff volume in cubic meters,

q_p = peak runoff rate in m^3/sec.

A method of estimating the amount of fines in the sediment yield from sheet and rill erosion begins by determining the amount of fines in the eroded soil. Fines move more easily than coarse materials, therefore, it can be assumed that the percent fines in the yield will be at least equal to the percent of fines in the eroded soil. The total fines can not exceed the sediment yield from this source or 100 percent of the yield. An evaluation of the grain size distribution of the eroded soils and an examination of the watershed will assist in determination of what value to select within that range.

The other sources of sediment that must be considered are gullies, stream banks and beds. Channel erosion is usually predicted on an average annual basis using procedures in NEH, Section 3, Sedimentation. The average annual value is then modified for a single storm. This will require considerable judgement on the part of the person making the estimate.

When estimating channel erosion from an individual storm, it is important to consider the availability of sediment stored in the channel or gully.

An estimate of the amount of fines in the sediment yield from channel types of erosion can be accomplished in the following manner. Determine from samples the percentage of the eroded material (bank and bed) that is finer than 0.074 mm. Because this sediment is in the delivery system of the watershed it can be assumed that most of the fines will be moved to the point of concern. Although the delivery ratio will vary with field conditions it can be expected to be high. Generally, stream delivery ratios for fine material might be in the range of 90 to 100 percent. Then it is a matter of multiplying the channel erosion by the estimated sediment delivery ratio and adjusting for the percent smaller than 0.074 mm.

When selecting the percentage of fines in the sediment yield from channel erosion it should be considered that many times the clay-size material is not transported as discrete particles, but as a clay aggregate whose transport behavior may be similar to that of sand-size material. The clay size analysis should be made in the natural water without dispersives to indicate the proportion of clay transported as discrete particles.

EXAMPLE

Data given

A 640 acre drainage area contributes sediment to the channel. Sheet and rill and gully erosion are common to the drainage area. Representative soil samples of the surface area subject to sheet and rill erosion indicate 45 percent finer than 0.074 mm. Gully bank (channel) samples indicate 29 percent finer than 0.074 mm.

The hydrologist has determined that for the 10-year storm the volume of runoff (Q) will be 45 acre-feet and the peak flow rate (q_p) will be 312 cfs.

Additional field data show a weighted average soil-erodibility factor (K) of 0.32; slope length-gradient factor (LS) of 0.35; crop management factor (C) of 0.45; erosion control practice factor (P) of 1.0.

Determine

1. Amount of fine sediment reaching design channel from 10-year storm.

2. Concentration of fine sediment in design channel.

Calculations

1. Total sediment yield from sheet and rill erosion to design channel.

   a. Use Modified Universal Soil Loss Equation for sediment yield resulting from sheet and rill erosion on 640 acres.

$$S = 95\ (Q \times q_p)^{0.56} \times K \times LS \times C \times P$$

$$S = 95\ (45 \times 312)^{0.56} \times 0.32 \times 0.35 \times 0.45 \times 1.0$$

S = 1,006 tons sediment yield resulting from sheet and rill erosion.

2. Amount of fine sediment reaching design channel from 10-year storm.

   a. Fines from sheet and rill erosion.

Forty-five percent of eroded soil is finer than 0.074 mm. If it is assumed that the sediment yield has the same grain size distribution as the eroded soil, then there would be forty-five percent of 1,006 tons of sediment finer than 0.074 mm or 453 tons. This assumption implies that all grain sizes have the same delivery ratio and it is realized that this is not a valid assumption. The figure of 453 tons is considered a minimum value. The maximum value would be 1,006 tons of sediment finer than 0.074 mm. An evaluation of the grain size distribution and examination of the watershed indicates that 85% of the sediment will be finer than 0.074 mm.

1006 tons sediment yield x 0.85 = 855 tons of fine sediment yield from sheet and rill erosion.

   b. Fines from gully erosion. Gully erosion has been estimated to be 100 tons and the sediment delivery ratio is 90 percent.

Sediment yield = erosion x sediment delivery ratio
= 100 tons x 0.90

Sediment yield = 90 tons from gully (channel) erosion

Twenty-nine percent of the eroding material is finer than 0.074 mm, therefore, it can be expected that the sediment yield will usually contain at least that percentage. Examination of the grain size distribution of the channel material being eroded, the channel network in the watershed, and the magnitude of flow indicate that 30 percent of the sediment yield will be finer than 0.074 mm.

90 tons sediment yield x 0.30 = 27 tons of fine sediment from channel erosion.

c. Total fine sediment reaching channel is:

855 tons from sheet and rill erosion
27 tons from gully (channel) erosion
882 tons finer than 0.074 mm

3. Average concentration of fine sediment in design channel.

a. Volume of water in flow: 45 acre-feet converted to weight is 62.4 x 21.78 x 45 or 61,158 tons.

b. Weight of material finer than 0.074 mm is 882 tons.

$$\bar{S} = \left(\frac{\text{Weight of sediment}}{\text{Weight of sediment + weight of water}}\right) 1{,}000{,}000$$

$$\bar{S} = \left(\frac{882}{882 + 61{,}158}\right) \times 1{,}000{,}000 = 14{,}216 \text{ ppm, say } 14{,}000 \text{ ppm}$$

4. Peak concentration of fine sediment in design channel.

$$S_p = 2.5 \left(\frac{\text{Weight of sediment}}{\text{Weight of sediment + weight of water}}\right) 1{,}000{,}000$$

or $S_p = 2.5$ (average concentration)

$$S_p = 2.5 \times 14{,}000 \text{ ppm} = 35{,}000 \text{ ppm}$$

The geologist furnishes these values for use in designing stable channels.

REFERENCES

1. Soil Conservation Service, Computer Program for Project Formulation - Hydrology. Technical Release No. 20, 1965.

2. Soil Conservation Service, Design of Open Channels. Technical Release No. 25, 1977.

3. Soil Conservation Service, National Engineering Handbook, Section 3, Sedimentation, 1971.

4. Soil Conservation Service, National Engineering Handbook, Section 4, Hydrology Chapter 16, 1972.

5. Soil Conservation Service, Procedure for Computing Sheet and Rill Erosion on Project Areas. Technical Release No. 51 (Rev. 2), 1977.

6. Soil Conservation Service, Urban Hydrology for Small Watersheds. Technical Release No. 55, 1975.

7. Soil Conservation Service, Guide to Sedimentation Investigations - TG-12. South Technical Service Center, 1976.

8. Williams, J.R., Sediment Yield Prediction with Universal Equation using Runoff Energy Factor, Present and Prospective Technology for Predicting Sediment Yields and Sources: Proceedings of the Sediment-Yield Workshop, ARS-S-40, pp. 244-252, USDA Sedimentation Laboratory, Oxford, Mississippi.

9. Soil Conservation Service, Procedure for Determining Rates of Land Damage, Land Depreciation, and volume of Sediment Produced by Gully Erosion. Technical Release No. 32, Geology, 1966.