Suspended-sediment Samplers. Suspended-sediment samplers can be classified as (1) depth-integrating, (2) point-integrating, (3) single-stage, or (4) pumping samplers. Depth-integrating samplers accumulate a water-sediment sample in a pint-size milk bottle as they are lowered to the stream bed and raised back to the surface at a uniform rate of transit. They are designed so that the velocity in the intake nozzle is nearly equal to the local stream velocity. Samples may be collected by wading in a stream, by hand from a suitable support, or mechanically with a cable-and-reel setup. The U.S. DH-48 sampler (4.5 lb) (Fig. 15-18) with wading-rod suspension is used in shallow streams when the product of flow depth (in feet) and mean velocity (in feet per second) does not exceed 10 [22]. The U.S. DH-59 sampler (24 lb) with hand-line suspension is used in streams with low velocities but with depths that do not permit samples to be collected by wading. The U.S. D-49 sampler (62 lb) with cable-and-reel suspension is designed for use in streams beyond the range of hand-operated equipment. Depth-integrating samplers were developed to improve sampling accuracy and to reduce the cost of collecting suspended-sediment data.

Point-integrating samplers accumulate a water-sediment sample that is representative of the mean concentration at any selected point in a stream during a short interval of time. The intake and exhaust characteristics of point-integrating samplers are identical to those of depth-integrating samplers. A rotary valve that opens and closes the sampler is operated by a solenoid energized by batteries at the surface. The current flows to the solenoid by a current-meter cable, which suspends the sampler. Point-integrating samplers can be used to collect depth-integrating samples by leaving the valve open as the sampler is moved through the stream vertical. This permits depth-integration in streams that are too deep to be appropriately sampled with a depth-integrating sampler. The U.S. P-46 and P-61 (100 lb), P-63 (200 lb), and P-50 (300 lb) point-integrating samplers are in current use.

The single-stage sampler was developed to obtain suspended sediment data in flashy streams, particularly those in remote areas [24]. It is used to sample sediment at a specific depth and on the rising stage only. The sampler operates on the siphon principle, and therefore the velocity in the intake is not equal to the stream velocity. With careful operation, the single-stage sampler can be used to obtain supplemental data on suspended-sediment concentration at selected points.

The pumping sampler does not require an operator and is designed to obtain a continuous record of sediment concentration by sampling at a fixed point at specific time intervals. The velocity in the intake is not equal to the stream velocity, and the intake does not meet the requirements of an ideal sampler, since it does not point into the flow. However, the pumping sampler can be calibrated by rating its measurements against those obtained with standard depth-integrating or point-integrating samplers.

Bed-load Samplers. Bed-load samplers are of three types: (1) basket type, (2) pan type, and (3) pressure-difference type. The basket and pan types cause an increase in resistance to flow and a reduction in stream velocity at the sampling location. The reduction in stream velocity interferes with the rate of bed-load transport, compromising the accuracy of the measurement. The pressure-difference bed-load sampler is designed to eliminate the reduction in velocity, resulting in increased sampling accuracy.

The efficiency of a bed-load sampler, i.e., the ratio of sampled bed load to that

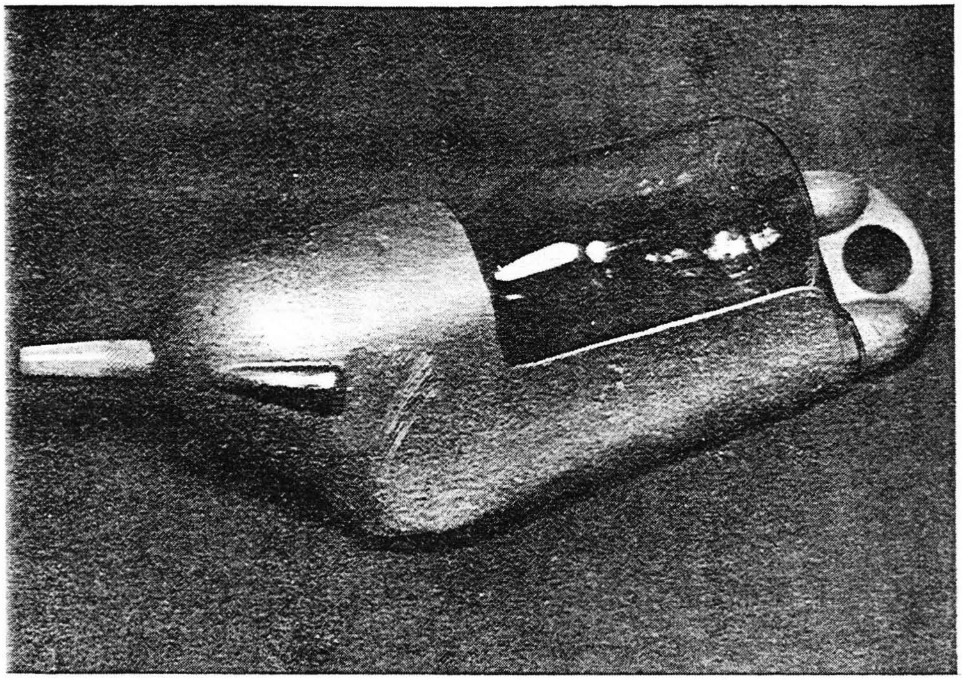

Figure 15-18 US DH-48 depth-integrating suspended-sediment sampler (photo courtesy of U.S. Geological Survey).

actually transported, varies with sample type, method of support, particle size, and bed configuration. Calibration of bed-load samplers has indicated a mean efficiency of about 45 percent for the basket and pan types and 70 percent for the pressure-difference type.

Bed-material Samplers. Bed-material samplers are of three types: (1) drag bucket, (2) grab bucket, and (3) vertical-pipe, or core sampler. The drag-bucket sampler consists of a weighted section of cylinder with an open mouth and cutting edge. As the sampler is dragged upstream along the bed, it collects a sample from the top layer of bed material. The grab-bucket sampler is similar to the drag-bucket, consisting of a cylinder section attached to a rod, and used primarily in shallow streams. The vertical-pipe, or core sampler, consists of a piece of metal or plastic pipe that can be forced into the stream by hand. Generally, the drag-bucket and grab-bucket samplers do not obtain representative samples of bed material because of the loss of fine material. The core sampler is satisfactory for use in shallow streams.

The U.S. BMH-53 sampler consists of a 9-in.-long, 2-in.-diameter brass or stainless steel pipe with a cutting edge and suction piston attached to a control rod. The piston is retracted as the cutting cylinder is forced into the stream bed. The partial vacuum that develops in the sampling chamber as the piston is withdrawn assists in holding the sample in the cylinder. The sampler can be used only in streams shallow enough to be waded.

The U.S. BMH-60 bed material sampler with both handline and cable suspension is designed to scoop up a sample of bed sediment about 3 in. wide and 2 in. deep. At the close of the sampling operation, the cutting edge rests against a rubber stop, which prevents any sediment from being lost. The aluminum sampler weighs 30 lb and the brass sampler, 40 lb. It is used to collect bed-material-sediment samples in streams with low velocities but with depths beyond the range of the BMH-53 sampler.

The U.S. BM-54 bed-material sampler (100 lb) with cable suspension is similar in design to the BHM-60 sampler. It is used in deep streams where a heavier sampler is necessary.

Suspended-sediment Discharge Measurements

Suspended-sediment samplers are used to determine sediment concentration at a point in a stream (i.e., a stream vertical), except for a small unmeasured zone located just above the stream bed. With wading equipment, measurements can generally be made down to within 0.3 ft of the stream bed. For cable-supported equipment, the unmeasured zone varies between 0.5 and 1.0 ft, depending on the size of sampler used.

Suspended-sediment discharge measurements include: (1) suspended-sediment concentration, (2) particle size, (3) specific gravity, (4) temperature of water-sediment mixture, (5) water discharge, and (6) distribution of flow in the stream cross section.

The streamflow depth and velocity and the facilities at the sampling site (bridge, cableway, and so on) have an influence on the choice of sampler. Stream depth determines whether hand samplers, such as the DH-48 or DH-59, or a cable-suspended sampler, such as the D-49, should be used. Flow depths over 15 ft require the use of point-integrating samplers to avoid overfilling of the sampling bottles. The larger the product of flow depth times mean velocity, the heavier the sample required for proper measurement.

The number of sampling verticals depends on the desired accuracy and the variation of sediment concentration across the stream. For streams with a stable cross section and essentially uniform sediment concentration across the width, sampling at a single vertical is usually adequate.

Depth-integrating samplers produce a suspended-sediment concentration, which can be measured in parts per million and converted to milligrams per liter. The suspended-sediment discharge is given by the following formula:

$$Q_s = 0.0027 C_s Q \tag{15-26}$$

in which Q_s = suspended sediment discharge in tons per day; C_s = suspended-sediment concentration in milligrams per liter; Q = water discharge in cubic feet per second, and 0.0027 is the conversion factor for the indicated units. Table 15-8 shows a factor to convert concentration in parts per million to milligrams per liter.

There are two techniques to measure suspended-sediment discharge: (1) EDI, or equal-discharge increments, and (2) ETR, or equal-transit rate. In the EDI method, sampling is done at the centroids of equal-discharge increments. In the ETR method, sampling is done at the centroids of equal-length increments. The EDI method requires a knowledge of the lateral distribution of streamflow prior to the selection of sampling verticals. The ETR method is applicable to shallow streams where the crosssectional distribution of streamflow is not stable. Generally, the EDI method requires fewer sampling verticals than the ETR method. The ETR method, however, does not require a prior discharge measurement. The suspended-sediment concentration in the EDI method is the average obtained from several depth-integrating samples. In the ETR method, the suspended sediment concentration is that of a composite sample encompassing several depth-integrating samples.

The error in suspended-sediment discharge provided by the measurement varies with the depth of the unsampled zone and the size distribution of suspended load. The error tends to be smallest in the cases where the vertical concentration gradient in the unsampled zone is small. The concentration gradient near the bed is small for silt and clay particles and large for coarser sand particles. Corrections in sampled suspended-sediment discharge to account for the unsampled portion are usually obtained through appropriate sediment transport predictors such as the Colby 1957 method or the modified Einstein procedure [7, 9].

QUESTIONS

1. Give two alternate definitions of particle sphericity.
2. What is the difference between specific weight and specific gravity?
3. What is standard fall velocity? What is standard fall diameter?
4. What is the difference between sediment production and sediment yield?
5. Describe the differences between normal and accelerated erosion.
6. Name four sources of sediment.
7. What is the rainfall factor R in the Universal Soil Loss Equation?
8. What is sediment-delivery ratio?
9. Why is sediment-delivery ratio inversely related to drainage-basin area?
10. Why are two formulas needed in the Dendy and Bolton approach to the computation of sediment yield?
11. Describe the classifications of sediment load based on (1) predominant mode of transport and (2) whether the particle sizes are represented on the channel bed.
12. What are possible forms of bed roughness in alluvial channels?
13. What is range of applicability of the Meyer-Peter formula for bed-load transport?
14. What is the basic difference between the Colby 1957 and Colby 1964 procedures for the computation of discharge of sands?
15. What is a sediment rating curve?
16. What is sediment routing?
17. What is the trap efficiency of a reservoir?
18. What is a debris basin?
19. Describe two techniques to measure suspended-sediment discharge. How do they differ in the evaluation of suspended-sediment concentration?

PROBLEMS

15-1. Calculate the fall velocity of a sediment particle using Stokes' law. Assume a diameter 0.1 mm, kinematic viscosity 1 centistoke, specific gravity 2.65.

15-2. Calculate the specific weight of a sediment deposit in a reservoir, after an elapsed time of 100 y, under moderate drawdown conditions. Assume the following mix of particle sizes: sand 55%, silt 30%, clay 15%.

15-3. Compute the average annual soil loss by the universal soil loss equation for a 300-ac watershed near Lexington, Kentucky, with the following conditions: (1) cropland, 250 ac, contoured, soil is Keen silt loam, slopes are 7% and 150 ft long, $C = 0.15$; (2) pasture, 50 acres, 75% canopy cover, 60% ground cover with grass, soil is Ida silt loam, slopes are 10% and 200 ft long.

15-4. Compute the average annual soil loss by the universal soil loss equation for a 1-mi^2 forested watershed near Bangor, Maine. The soil is Fayette silt loam, the slopes are 3% and 300 ft long, and the site is 80% covered by forest litter.

15-5. Using the Dendy and Bolton formula, calculate the sediment yield for a 25.9-km^2 watershed with 5 cm of mean annual runoff.

15-6. Determine whether a particle of 2-mm diameter is at rest under a 3-m flow depth and 0.0002 channel slope. Assume a specific gravity 2.65 and kinematic viscosity 1 centistoke.

15-7. Determine the form of bed roughness that is likely to prevail under the following flow conditions: mean velocity 3 ft/s, flow depth 8 ft, channel slope 0.0002, and mean particle diameter 0.3 mm.

15-8. Given the following flow characteristics: flow depth 9 ft, mean velocity 3 ft/s, channel slope 0.00015, mean particle diameter 0.4 mm, mean channel width 250 ft. Calculate the bed material transport rate by the Duboys formula.

15-9. Given the following flow characteristics: flow depth 3 ft, mean velocity 5 ft/s, energy slope 0.009, mean particle diameter 1.0 in., mean channel width 30 ft. Calculate the bed-material transport rate (in tons per day) by the Meyer-Peter formula.

15-10. Given the following flow characteristics: flow depth 5 ft, mean velocity 4 ft/s, mean channel width 180 ft, measured concentration of suspended bed-material discharge 200 ppm. Calculate the total bed-material discharge (in tons per day) by the Colby 1957 method.

15-11. Given the following flow characteristics: flow depth 5 ft, mean velocity 3 ft/s, median bed material size 0.3 mm, mean channel width 225 ft, water temperature 70°F, wash load concentration 300 ppm. Calculate the discharge of sands by the Colby 1964 method.

15-12. A reservoir is to be built with a total storage capacity of 50 hm^3. The contributing drainage basin is 800 km^2, and the mean annual runoff at the site is 200 mm. Assume well-graded sediment deposits with average specific weight 1400 kg/m^3. (a) How long will it take for the reservoir to lose 20% of its storage volume? (b) How long will it take for the reservoir to fill up with sediment? Estimate sediment yield by the Dendy and Bolton formula.

15-13. A reservoir is to be built with a total storage capacity of 120 hm^3. The contributing drainage basin is 425 km^2, and the mean annual runoff at the site is 45 mm. Assume coarse sediment deposits with average specific weight 13 kN/m^3. (a) How long will it take for the reservoir to lose 80% of its storage volume? (b) How long will it take for the reservoir to fill up with sediment? Estimate sediment yield by the Dendy and Bolton formula.

15-14. Derive the conversion factor 0.0027 in Eq. 15-26.

15-15. Calculate the suspended-sediment discharge (in tons per day) for the following cases: (1) suspended sediment concentration 100 ppm, water discharge 1200 ft^3/s, and (2) suspended sediment concentration 80,000 ppm, and water discharge 5000 ft^3/s.

15-16. Derive the unit conversion factor C in the following formula: $Q_s = CC_sQ$, in which Q_s is given in kilonewtons per day, C_s in milligrams per liter, and Q in cubic meters per second.

15-17. Calculate the suspended-sediment discharge (in kilonewtons per day) for a suspended-sediment concentration of 150 ppm and a flow of 68 m^3/s.

15-18. Calculate the suspended-sediment discharge (in kilonewtons per day) for a suspended-sediment concentration of 22,000 ppm and a flow of 155 m^3/s.

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