An American National Standard

Standard Guide for Monitoring Sediment in Watersheds[1]

This standard is issued under the fixed designation D 6145; the number immediately following the designation indicates the year of original adoption or, in the case of revision, the year of last revision. A number in parentheses indicates the year of last reapproval. A superscript epsilon (ε) indicates an editorial change since the last revision or reapproval.

INTRODUCTION

Soil erosion and resulting sedimentation is the major cause of nonpoint source pollution that threatens water resources. These impacts include: impaired aquatic habitat; destruction of sport and commercial fisheries and shellfisheries; lost reservoir capacity for flood control, power generation, and storage of potable water supplies; excessive flooding; impaired navigation; aggradation of irrigation and drainage channels; lost productivity of lands swamped by deposition and infertile overwash; increased levels of water treatment; lost or declined recreational opportunities; and impaired aesthetic values. The amount of sediment in a stream can affect channel shape, sinuosity, and the relative balance between riffles and pools. Excessive sediment in a stream causes a decrease in channel capacity which in turn results in more frequent and larger out of bank floods. In addition to the adverse physical effects of sediment loads, many nutrients, pesticides, and heavy metals are sorbed onto fine sediment particles which may result in eutrophic or toxic waters. Indirect effects of increased sediment loads may include increased stream temperatures and decreased intergravel dissolved oxygen levels.

This guide recommends a process for developing and implementing monitoring projects for sediment in a watershed. It follows Guide D 5851 with more specifics applicable to watersheds and sediment.

These guidelines are presented for use in the nationwide strategy for monitoring developed by the Intergovernmental Task Force on Monitoring (ITFM). The nationwide monitoring strategy is an effort to improve the technical aspects of water monitoring to support sound water-quality decision-making. It is needed to integrate monitoring activities more effectively and economically and to achieve a better return of investments in monitoring projects **(1)**[2].

This guide is offered as a guide for standardizing methods used in projects to monitor and evaluate actual and potential nonpoint and point source sediment pollution within a watershed. The guide is applicable to landscapes and surface water resources, recognizing the need for a comprehensive understanding of naturally occurring and manmade impacts to the entire watershed hydrologic system.

1. Scope

1.1 *Purpose*—This guide is intended to provide general guidance on a watershed monitoring program directed toward sediment. The guide offers a series of general steps without setting forth a specific course of action. It gives advice for establishing a monitoring program, not an implementation program.

1.2 Sedimentation as referred to in this guide is the detachment, entrainment, transportation, and deposition of eroded soil and rock particles. Specific types or parameters of sediment may include: suspended sediment, bedload, bed material, turbidity, wash load, sediment concentration, total load, sediment deposits, particle size distribution, sediment volumes and particle chemistry. Monitoring may include not only sediments suspended in water but sediments deposited in fields, floodplains, and channel bottoms.

1.3 This guide applies to surface waters as found in streams and rivers; lakes, ponds, reservoirs, estuaries, and wetlands.

1.4 *Limitations*—This guide does not establish a standard procedure to follow in all situations and it does not cover the detail necessary to define all of the needs of a particular monitoring objective or project. Other standards and guides included in the reference and standard sections describe in detail the procedures, equipment, operations, and site selection for collecting, measuring, analyzing, and monitoring sediment and related constituants.

1.5 Additional ASTM and US Geological Survey standards applicable to sediment monitoring are listed in Appendix X1 and Appendix X2. Due to the large number of optional

[1] This test method is under the jurisdiction of ASTM Committee D19 on Water and is the direct responsibility of Subcommittee D19.02 on General Specifications, Technical Resources, and Statistical Methods.

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[2] The boldface numbers given in parentheses refer to a list of references at the end of this standard.

standards and procedures involved in sediment monitoring, most individual standards are not referenced in this document. Standards and procedures have been grouped in the appendices according to the type of analyses or sampling that would be required for a specific type of measurement or monitoring.

1.6 *This standard does not purport to address all of the safety concerns, if any, associated with its use. It is the responsibility of the user of this standard to establish appropriate safety and health practices and determine the applicability of regulatory limitations prior to use.*

2. Referenced Documents

2.1 *ASTM Standards:*

D 1129 Terminology Relating to Water[3]

D 4410 Terminology for Fluvial Sediment[3]

D 4411 Guide for Sampling Fluvial Sediment in Motion[4]

D 4581 Guide for Measurement of Morphologic Characteristics of Surface Water Bodies[4]

D 4823 Guide for Core-Sampling Submerged, Unconsolidated Sediments[4]

D 5851 Guide for Planning and Implementing a Water Monitoring Program[4]

3. Terminology

3.1 *Definitions:*

3.1.1 For definitions of terms used in this guide, refer to Definitions D 1129 and Terminology D 4410.

3.2 *Definitions of Terms Specific to This Standard:*

3.2.1 *assess*—to determine the significance, value, and importance of the data collected and recorded.

3.2.2 *best management practice (BMP)*—a practice or combination of practices that are determined by state or area-wide planning agencies to be the most effective and practical means of controlling point and nonpoint pollution.

3.2.3 *hydrograph*—a graphical representation of the discharge, stage, velocity, available power, or other property of stream flow at a point with respect to time.

3.2.4 *measurement*—determining the value of a characteristic within a representative sample or in situ determinations of selected components of riverine, lacustrine, or estuarine systems.

3.2.5 *nonpoint source pollution*—a condition of water within a water body caused by the presence of undesirable materials that enter the water system from diffuse locations with no particular point of origin.

3.2.6 *resource management system (RMS)*—A combination of conservation practices identified by the primary use of the land that will protect the soil resource base, maintain acceptable water quality, and maintain acceptable ecological and management levels for the selected resource use.

3.2.7 *watershed*—all lands enclosed by a continuous hydrologic surface drainage divide and lying upslope from a specified point on a stream.

4. Significance and Use

4.1 This guide is intended to be used in the planning stage or phase of developing a sediment monitoring program. This guide is an assembly of the components common to all aspects of watershed sediment monitoring and fulfills a need in the development of a common framework for a better coordinated and a more unified approach to sediment monitoring in watersheds.

4.2 The user of this guide is not assumed to be a trained technical practitioner in the water quality, sedimentation, or hydrology fields. The intended users are managers and planners who need information to develop a water quality monitoring program or project with an emphasis in sediment and hydrology. Sediment specialists will also find information on procedures, equipment, methodology, and operations to conduct a monitoring program.

4.3 This guide is used during the planning process of developing, designing, and reevaluating a sediment monitoring program.

5. Monitoring Purpose

5.1 A watershed monitoring program for sediment is comprised of a series of steps designed to collect sediment and related flow data in order to achieve a stated objective. The purposes of monitoring may be several and include: analyzing trends, establishing baseline conditions, studying the fate and transport of sediment and associated pollutants, defining critical source areas, assessing compliance, measuring the effectiveness of management practices, project monitoring, implementation monitoring, making wasteload allocations, testing models, defining a water quality problem, and conducting research.

5.2 Monitoring to analyze trends is used to determine how water quality or sediment load changes over time. Normally, measurements will be made at regular well-spaced time intervals in order to determine the long term trend in some sedimentation parameter. Typically the observations are not taken specifically to evaluate BMPs or management activities, water quality models, or water quality standards, although trend data may be utilized, in part, for one of these other purposes.

5.3 Baseline monitoring is used to characterize existing sediment or water quality conditions, and to establish a data base for planning or future comparisons. Baseline monitoring should capture as much of the temporal variations as possible in order to assess seasonal and long term climatic influences upon runoff and sediment yield. In some cases baseline monitoring is included as the early stage of trend monitoring.

5.4 Fate and transport monitoring is conducted to determine whether sediment and associated pollutants move and where they may go.

5.5 Sediment monitoring can be used to locate critical source areas within watersheds exhibiting greater pollution or loading potential than other areas.

5.6 Sediment monitoring may also be used to assess compliance with water quality management plans or standards. This is the monitoring used to determine whether specified

[3] *Annual Book of ASTM Standards*, Vol 11.01.

[4] *Annual Book of ASTM Standards*, Vol 11.02.

water-quality criteria are being met. The criteria may be numerical (quantitative) or descriptive (qualitative).

5.7 Sediment monitoring may assess the effectiveness of individual management practices or resource management systems for improving water quality or, in some cases, may be used to evaluate the effect of an entire program in a watershed. Evaluating individual BMPs may require detailed and specialized measurements made at the practice site or immediately adjacent to the management practice. Monitoring the overall effectiveness of BMPs is usually done in the stream channel and it may be difficult to relate measured values to individual practices.

5.8 Implementation monitoring may assess whether BMPs were installed or implemented, or if significant land uses changes occurred. Typically this activity is carried out as an administrative review or a monitoring of landuse changes. On its own, however, implementation monitoring cannot directly link management activities to water quality or sediment yield, as no actual sediment or water measurements were taken.

5.9 Monitoring of water bodies receiving runoff and sediment or other suspended loads can be used to make wasteload allocations between various point and nonpoint sources. Such allocations require good knowledge of the individual contributions from each source.

5.10 Sediment monitoring may be used to fit, calibrate, or test a model for local conditions. Sediment monitoring may be used to evaluate samplers, rainfall simulators, runoff collection devices and other related instruments or devices for research purposes.

5.11 Finally, sediment monitoring may be used to give adequate definition to a water quality problem or determine whether a sediment related problem exists.

5.12 Guide D 5851 provides overall guidance on water monitoring and provides detailed information on purposes of monitoring water quality. Additional information on purposes of watershed monitoring is provided in USDA-NRCS Water Quality Monitoring Handbook **(2)**, the ITFM reports **(1, 3, 4, 5)**, and EPA Guidelines **(6, 7)**.

6. Monitoring Components

6.1 This guide suggests and discusses the following steps in designing a watershed monitoring program for sediment. More detail on each step may be found in USDA-NRCS Monitoring Handbook **(2)**.

6.1.1 *Identify Need*—The first step is to define the need for water quality monitoring. The need statement should include several components: the potential or real water quality issue requiring attention, the potential use impairment or threats, the name of the actual water resource(s), and finally the potential sources that may cause the problem(s) **(2)**. Very often the need is to identify a water quality problem but in some cases, the need may be to assess the existing water quality whether a problem exists or not. An example of a need statement might be: "The decline in shellfish in Big Bay is due to accelerated sedimentation caused by excessive erosion from forestry operations within the Trout Brook watershed". Since sediment may originate or become resuspended from a vast variety of nonpoint and point sources, the cause(s) of the sediment problem may be difficult to establish or distinguish unless detailed monitoring plans are implemented.

6.2 *Monitoring Objectives*—The second step in developing a sediment monitoring program is to define the monitoring objectives. The objectives of the monitoring study should address the water quality need or problem. An objective statement should include an infinitive verb, an object word or phrase, and some constraints on the objective such as the surface or ground water watershed boundaries and variables to monitor. An example of a monitoring objective might be: "To determine the effect of implementing best management practices on sediment concentration or sediment yield in Trout Brook". When several objectives are used, a hierarchical approach may be used to determine higher priority objectives. An objective tree can be used to distinguish among several objectives. To determine how several objectives can be linked, the following question can be asked: "Does the achievement of objective A contribute directly to the achievement of objective B"? To assess whether objectives are being achieved, objective attributes could be determined. These attributes may be binary, achieved or not, or scaler.

6.3 *Sampling Design*—A wide variety of instruments and techniques have been developed for field measurements of soil erosion, sediment movement, turbidity, and sediment deposition. In general four basic types of studies exist: measurements of sediment in surface runoff from small experimental plots and field size watersheds, stream sampling of suspended sediment load and bedload, measurements of eroded areas to determine volume of material removed, and measurements of the volume and density of deposited sediment. All four studies may also include particle size analyses and chemistry of the sediments and associated pollutants. A statistical experimental design should be stated that is consistent with the objectives of the monitoring program. Appropriate experimental designs for monitoring sediment in motion or suspended sediment could include: reconnaissance, plot, single watershed" above-and-below", single watershed "before-and-after", paired watersheds, multiple watersheds, and trend stations **(2)**.

6.3.1 The design selected will dictate most other aspects of the monitoring project including the study scale, the number of sampling locations, the sampling frequency, and the station type.

6.3.1.1 Reconnaissance or synoptic designs may be used as a preliminary survey where no data exist or to assess the magnitude and extent of a problem. This type of sampling could be used to identify critical source or problem areas as well. Randomization in sampling locations may be important for reconnaissance monitoring.

6.3.2 Plot designs have been commonly used in agricultural and forestry experiments for 100 years. Plots are generally small areas that allow replication and control on the landscape of certain variables, such as soil type, slope, and land cover. Plot studies can utilize natural rainfall events or artificial rainfall simulators (eg rainulators). Plot studies are best utilized for evaluating individual BMPs, developing model algorithms, and evaluating specific soil, climatic, and physiographic variables. Plot designs are generally analyzed using analysis of variance **(2)**.

6.3.3 The single watershed "before-and-after" approach has been sometimes used to compare water quality conditions before an application of BMPs or landuse changes to conditions after activity has occurred. Generally, this technique is not recommended, since the results are confounded with time, and should be avoided. For example, the water quality differences from year-to-year may be caused by climate differences not the watershed activity or land use management.

6.3.4 The single watershed "above-and-below" design is used after a watershed practice is in place. Sampling is conducted both upstream and downstream from the activity of interest. Although this design is not as susceptible to the effect of climate as the single watershed design, the differences in water quality between the two stations may be partly due to inherent watershed differences such as soil type, land gradient, geologic materials, or varying watershed runoff characteristics, or all of these.

6.3.5 The paired watershed approach uses a minimum of two watersheds – control and treatment – and two periods of study– calibration and treatment **(8)**. The control watershed serves as a check and provides information on the effects of year-to-year climate variations and receives no changes in land uses or activities during the monitoring study. During calibration, the two watersheds are managed or treated identically and paired water quality data are collected. During the treatment period, one watershed is treated with a practice or management system while the control watershed remains in the original management.

6.3.6 The multiple watershed approach involves more than two watersheds. Watersheds with treatments already in place are selected from across the region of interest. Sampling from these watersheds is conducted over a period of time. Groups of like watersheds are tested against each other to determine water quality differences **(2)**.

6.3.7 Trend stations are single watersheds monitored over time. A trend is a persistent change in the water quality variables of interest over time. It is important for trend analysis that there not be gaps in the data set, that water quality analysis methods not change, that the hydrological control is stable, and a causal link can be made between the water quality and watershed activities. A control trend station is highly recommended where no changes in watershed activities occur during the trend investigation **(2)**.

6.3.8 In addition to erosion and sediment yield studies from plot and field size watersheds, sediment investigations in a land resource area may require measurements of sediment yield from channels, gullies, and other major or critical sediment sources. Typical sites may not exist, but sites selected should represent local conditions as nearly as possible. Often these studies require detailed topographic surveys in order to determine volumes of material eroded.

6.3.9 Sampling of sediment deposited in stream beds and valley bottoms is used to provide information on sediment particle size distribution, specific gravity, mineralogy of the sediment particles, sediment volumes, effects on benthic ecosystems, sorbed toxic chemicals, and nutrients. The most common purpose for sampling sediment deposits in streams is to obtain information on the character of the sediment particles that are subject to movement during storm runoff events. This information is needed for channel stability analyses, sediment transport studies, and assessing the effects of bed scour and deposition upon bethic organisms.

6.3.10 Sampling of reservoir and lake deposits often provides information on the sediment yield and sediment characteristics of an entire watershed. Most reservoir sedimentation studies are directed toward determining the quantity, characteristics, and distribution of sediment as determined by periodic volumetric surveys of the lake or reservoir. Reservoirs are normally surveyed to determine rate of sediment buildup and assess remaining useful reservoir life or water storage, determine sediment yield from a watershed that represents a typical landuse pattern in a region or land resource area, evaluate the effects of watershed protection measures, determine sediment yield of unusually large storms, determine long term regional sediment yields, provide basic data for planning and designing reservoirs, monitor quality, and evaluate sediment damages. Reservoir sedimentation investigations may be part of single watershed, paired watershed, multiple watershed, or trend station study approaches. In addition, determination and evaluation of reservoir trap efficiencies can be made if inflow or outflow sediment measurements, or both, are made or are available.

6.4 *Study Scale*—The size or scale of the monitoring program should be determined. Appropriate scales include: point, plot, field, and watershed.

6.4.1 Points are the smallest scale considered for water quality monitoring and are characterized by obtaining single observations. A rain gage, a sediment probe, or a staff gage represents a point sample.

6.4.2 Plots are microcosm sampling units which are appropriate if the objective is to replicate several treatments or activities. Generally, fractional acre (hectare) plots are used to study basic erosion rates and edge of plot sediment yield of various soil cover complexes with various BMPs installed. Replicate plots are often required to obtain representative data due to such factors as inherent errors in measurement and natural variations within soil units. The number of plots needed for a study is a function of the number of treatments applied **(2)**. For most experiments, ten or more years of study is required in order to cover the normal range in weather patterns. Utilizing rainfall simulators can greatly reduce the evaluation period or allow greater numbers of test to be performed in a short period of time. Detailed information on designing plot studies may be found in Ref **(9)**.

6.4.3 Monitoring on a field scale implies a larger area than an individual plot. The area of a field is difficult to state because it varies greatly in different parts of the United States. Field scale monitoring is normally used to determine erosion rates and edge of field (mini-watershed) sediment yield from tracts of land a few acres (hectares) in size which are representative of given land resource area under specific land use and management with or without BMPs installed.

6.4.4 Watershed scale monitoring is used for most water quality monitoring purposes. One of the most difficult decisions is the watershed size. Generally, size is influenced by stream order, climate, number of landowners, homogeneity in land use and physical attributes, and geology **(2)**. If a determination of sediment yield from a watershed or river-basin is the only objective, any size watershed is appropriate, however smaller watersheds will require more frequent measurements due to more rapid and extreme temporal variations in runoff. In order to assess the effects of land use, land management, BMP installations, or other activities, the sampling stations should be as close to the activity as possible. This will often dictate the size of the watershed to be monitored.

6.5 *Variables*—Since sedimentation processes are complexly linked to the quantity and character of runoff, it is often necessary that fluvial sedimentation data be associated with corresponding runoff data for many interpretative analyses. A list of the sediment parameters to measure should be indicated. Typical parameters can include: turbidity, sediment concentration, sediment particle size distribution, sediment particle shape, particle mineralogy, sediment volume, sediment density, sediment yield, suspended load, bed load, bed material, total load, and "sorbed" or associated pollutants. Sediment monitoring often requires that additional supporting or related parameters be monitored such as discharge, stream velocity, and some chemical parameters associated with point and nonpoint source pollution. Typically associated pollutants include: pesticides, nutrients, heavy metals, materials from toxic spills, sludge components, TOC (total organic carbon), BOD (biochemical oxygen demand) or COD (chemical oxygen demand) materials. Also several biological characteristics of the water may need to be monitored since they are affected by sediment movement and deposition in the streams and the entire watershed. Often, water quality indices or environmental indicators may be used for sediment monitoring in watersheds. Water quality variable selection depends on the objectives, water body type, the use of the water, the land activity being investigated, the cost or difficulty in analysis, and any issue associated with the water body. Other techniques for selection include ranking the variables of interest, developing correlations between variables, and determining the probability of exceeding a standard **(2)**.

6.6 *Sample Type*—Sediments in watersheds may be collected and measured as either; total water and sediment runoff; portioned or fractional runoff; grab; composite; integrated; or continuous samples. The type of sample collected is a function of the purpose in monitoring, the variables to sample, and whether turbidity, concentration, total yield or mass is the desired outcome.

6.6.1 Total collection devices are often used on very small plots where a suitable collection tank large enough to contain the total runoff (water and sediment) expected in a 24 or 48 h period can be installed **(9)**. Total collection devices are normally not recommended because runoff storage volumes are excessive even for very small drainage areas. Also small plots may not be representative of larger complex fields and small watershed conditions.

6.6.2 Slot type or portioned samplers, which collect a known portion of the runoff-sediment mixture, are often better suited for larger plots and small fields. These samplers are automatic in the sense that no attendant is required during the sampling operation and sampling is continuous during the runoff event. The samplers provide a storm integrated or discharge weighted sample for determining sediment yield. Construction, installation and operation details for total collection and slot type samplers can be found in Ref **(9)**.

6.6.3 A grab sample is a discrete sample that is taken at a specific point and time. A series of grab samples, usually collected at different times or locations in a stream cross-section, and lumped together, are considered a composite sample. Composite samples may be either time-weighted or flow-weighted. A specific type of a grab sample is a depth-integrated sample. Such samples account for velocity or stratification induced differences in water quality. Most sediment sampling of streams, lakes, estuaries, and land surfaces is performed with grab samplers and grab sample techniques. Numerous sampling devices and techniques have been developed for sampling: suspended sediment in streams, lakes and estuaries; bedload sediment in streams and estuaries; and deposited sediment in reservoirs, streams, and land surfaces. If sediment yield information is one of the desired parameters, intensive stream-flow measurements or monitoring will be required in addition to collecting suspended or deposited sediment samples.

6.6.4 Continuous sampling or measurement is not common but usually involves water quality variables measured using electrometric methods, such as specific ion electrodes for conductivity (dissolved solids) and fine suspended solids. Continuous water level recording devices are commonly used to compute stream water elevations which in turn are used for stream discharge and sediment yield computations. Elaborate continuous bedload sampling schemes and apparatuses utilizing semi-permanent trenches constructed across the entire stream bed, conveyors, large diameter pipelines, and settling ponds have been used by researchers to measure total bedload movement in coarse-gravel and cobble bed streams **(11)**.

6.7 *Sampling Location*—The location of sampling should be determined at two levels: where within the watershed and where at a given station location. The monitoring program objectives, study design, and type of water body will dictate general sampling locations. To characterize a watershed outlet only requires one station. To identify, quantify or qualify sediment sources in a watershed or to make lake or estuary characterizations would require many more locations. Detailed information and guidance on locating gaging and monitoring stations can be found in the referenced ASTM standards, USGS TWRIs, and Agricultural Handbook 224 **(9)**. Additional information may be found in references listed at the end of this guide.

6.7.1 Once the overall location has been determined, a more specific location is needed to collect a representative sample. Sediments are known to stratify in streams, reservoirs, lakes, and estuaries. Therefore, sampling at different depths will yield different results. Gradients across streams may also exist due to velocity and therefore sediment gradients. Width gradients may be especially evident below the confluence of two streams. Algae also may stratify in water bodies which in turn may effect turbidity measurements. Sampling within stratified systems is often done on an integrated basis. Details on sampling streams using depth and width integation techniques may be found in the referenced ASTM standards, TWRI methods, AH-224 **(9)**, and USGS Openfile Report 86-531 **(10)**.

6.8 *Sampling Frequency and Duration*—The sampling frequency should be based on the objectives of the study, the type of sediment and watershed being monitored, and the variability in the data being collected. Sediment data are highly variable in most surface water systems due to the influence of precipitation and seasonal variations in ground cover. Sediment monitoring on plots and field size watersheds will normally gather runoff and sediment data continuously during all but the largest rainfall events which will overwhelm or exceed the capacity of the sampling devices. When monitoring sediment in streams, the primary objective is to obtain a sample or group of samples that are representative of the fluvial sediment in the flow cross section. The ultimate objective is to define, as accurately as possible, the trend with time of both the sediment concentration and sediment discharge. Sediment discharge is the summation of the incremental products of flow, concentration, and time. Since sediment concentration is not constant during storm runoff events, sampling frequency should vary in order to determine sediment discharge over the entire hydrograph. For example, on the rising side of the hydrograph the sediment concentration is usually greater and changes more rapidly, thus requiring more frequent sampling than the falling stage. A sampling frequency guide and related considerations may be found in Chapter 3 of Agricultural Handbook 224 **(9)**. On intermediate and large size watersheds, the sediment-transport curve/flow-duration curve method may be used. Initially numerous samples are needed at all stages for several small, medium and large flow events, thereafter occasional samples are needed to determine significant shifts in the original relationship. To determine the sampling frequency a sample size calculation should be made based on the estimate of the standard deviation, the allowable difference from the mean, and Student's t **(2)**. Such calculations are found in most standard statistical books. Calculations can also be made for detecting linear or step trends **(11)**. The duration of the study will also be influenced by the study objectives.

6.9 *Station Type*—Watershed monitoring of sediment may require the design and construction of monitoring stations for suspended sediment sampling, bed load and bed material sampling, turbidity, stream discharge, precipitation collection, biota, and particle size distribution. Reservoir and lake sediment surveys require the establishment of horizonal and vertical control points in order to conduct topographic surveys of lake bottoms and sediment deposits. The monitoring program should specify what types of monitoring stations will be used. Generally, several optional methods for conducting the monitoring are available for each type of monitoring station needed. USDA Agricultural Handbook No. 224 **(9)**, ASTM Standards, and US Geological Survey Techniques of Water Resources Investigations (TWRI) provide detailed information on designing monitoring stations. Other guidelines may be found in USDA-NRCS Water Quality Monitoring Handbook **(2)**.

6.10 *Sample Collection and Analysis Methods*—The sample collection procedures for sediment analysis will depend upon the type of sample and type of water resource being sampled. Sediment samples can be broadly classified into six general categories: storm integrated samples, suspended sediment samples, bedload samples, bed and bank samples, samples of reservoir, lake and valley (flood-plain) deposits, and samples of flume and approach channel deposits. The monitoring study should address appropriate techniques for collecting and analyzing samples.

6.10.1 *Storm Integrated Samples*—Samples collected with total or portioned (slot type) samplers are storm integrated and represent a sample of an entire runoff event.

6.10.2 Suspended sediment samples may be point samples, single vertical samples or multiple vertical samples; and may be representative of the total or only a portion of the suspended sediment load. The purpose of the monitoring study will influence whether discharge weighted samples are analyzed separately or combined/composited. Normally samples are combined if determination of suspended sediment discharge is the only objective. If sediment distribution within a stream cross section is required, samples must be analyzed separately. Procedures for suspended sediment sampling can be found is various TWRI methods, USGS Open File Report 86-531 **(10)**, AH-224 **(9)**, ASTM Standard Guides, and **(12)**.

6.10.3 *Bedload Samples*—Bedload samples are normally coarse grained (high in sand, gravel and cobble content) and are usually collected for the purpose of determining particle size distribution of the bedload and/or the bedload discharge of a stream. Sampling equipment and techniques are discussed in Guide D 4411, AH-224 **(9)**, and **(13)**.

6.10.4 *Bed and Bank Samples*—Samples of streambank and streambed materials may be collected in a disturbed or undisturbed state. Disturbed samples are usually collected to determine particle size distribution, organic content, specific gravity, Atterberg limits, particle mineralogy and other physical and chemical characteristics. Undisturbed samples are required for bulk density determinations, erosion resistance characteristics, soil strength determinations, permeability, and some chemical sampling. Bed material sampling procedures and equipment are discussed in AH-224 **(9)**, ASTM standards and guides, **(14)**, and **(15)**.

6.10.5 *Samples of Lake, Reservoir, Estuary and Valley Deposits*—Sediment deposited in lakes, reservoirs, and on valley floors can be sampled for both volumetric (quantitative) and qualitative (physical and chemical) analyses. Analyses of both disturbed and undisturbed samples may be required. The exact location where samples were obtained is important in computation of sediment weight in lakes and reservoirs. Equipment for sampling deposited sediment are discussed in Guide D 4823. Procedures for sampling, monitoring and measuring sediment in lakes and reservoirs are referenced in Guide D 4581.

6.10.6 *Sediment Deposits in Flumes and Approach Channels*—In erosion and sediment yield studies on plots and small field size watersheds, significant quantities of sediment are deposited in flumes and approach channels. This material should be sampled, measured or weighed, or both, to determine the portion of dry material per weight or per unit volume; and this weight added to the sediment discharge measured through the flume or other measuring device.

6.10.7 Many physical and chemical properties or parameters of sediment may be sampled, measured, and analyzed as mentioned in 6.5 of this guide. Numerous methods of analyses can be found in ASTM standards and guides, TWRIs, AH-224 **(9)**, ARS S-40 **(16)**, SCS National Engineering Handbook-NEH-3 **(17)**, and Federal Interagency Sedimentation Project study methods.

6.10.8 Transportation and storage of sediment samples before analysis should follow standard methods **(18)** and ASTM referenced methods. Most water-sediment samples collected for chemical analyses are chilled and transported in the dark and in coolers. The methods of laboratory analysis should be specified **(19)**.

6.10.9 The analysis methods should include a quality assurance/quality control program. Quality assurance is the total integrated program for assuring the reliability of monitoring and measurement data. Quality assurance is composed of quality control and quality assessment. Quality control refers to activities conducted to provide high quality data. Quality assessment refers to techniques used to evaluate the effectiveness of the program. A good quality control program should include good laboratory practices, standard operating procedures, education and training, and supervision. Quality assessment allows feedback on how well the quality control program is operating. Indicators of data quality include precision, accuracy, representativeness, comparability, and completeness. Usually such assessment involves the use of duplicate samples, spikes, internal and external audits, tests of reason, and exchange samples **(2)**.

6.11 *Land-Use Monitoring*—Since sediment can come from so many sources, it is critical to monitor the sources of these particles and associated chemicals in order to explain any sediment yield or water quality changes that may occur. Such sources may include: sheet and rill erosion, gully erosion, bank erosion, channel scour, flood plain scour, resuspension of previously deposited sediment, mining activities, municipal runoff, outfall and sludge disposal. The proximity of these sources to the water body may also be important. The land-use monitoring plan should match the monitoring objectives and be consistent with the watershed boundaries being monitored. The basic approaches for monitoring land use information are personal observations, field logs, personal interviews, and remote sensing. As the size of the study area increases, the difficulty and importance of adequate land-use monitoring become more important.

6.11.1 A method for managing land use data should be specified and could include ad hoc files, spreadsheets or data bases, or a geographic information system (GIS).

6.12 *Data Management*—The final step in developing a monitoring program for sediment in watersheds involves specifying the methods for the acquisition, storage, validation, retrieval, and manipulation of sediment and any related flow, precipitation and associated pollutant data. Acquisition includes the collection and entry into the data management system. Field data loggers have eased the complexity of this step. The storage of data should be viewed as a multilevel effort using both manual and computerized technologies. Original paper copies of collected data, if utilized, should be kept and maintained. All data should be validated with a 100 % error check. Tests of reason can be used in computes or manually to see if recorded values are even possible. Data generally require some form of manipulation before being reported. Manipulation may be statistical, graphical or may include censoring values below detection limits.

6.13 *Reporting*—Reporting of sediment data is no different than other water quality data and the guidelines specified in Guide (D 5851), should be followed.

6.14 *Re-evaluation Process*—Collaborative (interdisciplinary) teams should meet periodically to evaluate their monitoring activities to determine if the objectives of the program have been met and if the activities are proceeding in the most effective and economical manner.

7. Keywords

7.1 best management practices; BMP; environmental indicators; estuary; lakes; monitoring; nonpoint source pollution; point source pollution; reservoirs; sediment; sediment monitoring; sediment transport; surface water; water monitoring; water quality; water quantity; watershed; watershed monitoring

APPENDIXES

(Nonmandatory Information)

X1. ASTM STANDARDS RELATED TO SEDIMENT AND FLUVIAL HYDROLOGY

X1.1 ASTM Standards Addressing Stream Discharge (Flow) and Fluvial Hydrology

D 1941 Test Method for Open Channel Flow Measurement of Water With the Parshall Flume[3]
D 3858 Flow Measurement by Velocity-Area Method[3]
D 4409 Velocity Measurements with Rotating-Element Current Meters[3]
D 5089 Test Method for Velocity Measurements in Water in Open Channels with Electromagnetic Current Meters[3]
D 5129 Test method for Open Channel Flow Measurement of Water Indirectly by Using Width Contractions[3]
D 5130 Test Method for Open-Channel Flow Measurement of Water Indirectly by Slope-Area Method[3]
D 5242 Test Method for Open-Channel Flow Measurement of Water with Thin-Plate Weirs[3]
D 5243 Test Method for Open-Channel Flow Measurement of Water Indirectly at Culverts[3]
D 5388 Test Method for Measurement of Discharge by Step-Backwater Method[3]
D 5389 Test Method for Open Channel Flow Measurement by Acoustic Velocity Meter Systems[3]

D 5390 Test Method for Open Channel Flow Measurement of Water with Palmer-Bowlus Flumes[3]
D 5674 Guide for Operation of Stream Gaging Station

X1.2 ASTM Standards Addressing Suspended Sediment, Fluvial Sediment or Turbidity

D 1889 Test Method of Turbidity of Water[3]
D 3977 Practice for Determining Suspended-Sediment Concentration in Water Samples[3]
D 4410 Terminology for Fluvial Sediment[3]
D 4411 Guide for Sampling Fluvial Sediment in Motion[4]
D 4822 Guide for Selection of Methods of Particle Size Analysis of Fluvial Sediments (Manual Methods)[4]

X1.3 ASTM Standards Addressing Deposited Sediment, Reservoir Sedimentation or Bathymetric Surveys[5]

D 4581 Guide for Measurement of Morphologic Characteristics of Surface Water Bodies[4]
D 4823 Guide for Core-Sampling Submerged, Unconsolidated Sediments[4]
D 5073 Practice for Depth Measurement of Surface Water[4]
D 5387 Guide for Elements of a Complete Data Set for Noncohesive Sediments[5]

[5] Available from ASTM Headquarters.

X1.4 ASTM Addressing Laboratory Testing and Chemical Analysis of Sediments

D 3370 Practices for Sampling Water[3]
D 3856 Guide for Good Laboratory Practices in Laboratories Engaged in Sampling and Analysis of Water[3]
D 3974 Practices for Extraction of Trace Elements from Sediments[4]
D 3975 Practice for Development and Use (Preparation) of Samples for Collaborative Testing of Methods for Analysis of Sediments[4]
D 3976 Practice for Preparation of Sediment Samples for Chemical Analysis[4]
D 4183 Test Methods for Total Recoverable Phosphorus and Organic Phosphorus in Sediments[4]
D 4698 Practice for Total Digestion of Sediment Samples for Chemical Analysis of Various Metals[4]
D 4840 Practice for Sampling Chain of Custody Procedures[3]
D 5074 Practice for Preparation of Natural-Matrix Sediment Reference Samples for Major and Trace Inorganic Constituent Analysis by Partial Extraction Procedures[4]
D 5258 Practice for Acid-Extraction of Elements from Sediments Using Closed Vessel Microwave Heating[4]
D 5851 Guide for Planning and Implementing a Water Monitoring Program[4]

X1.5 Other ASTM Documents

Compilation of Scopes of ASTM Standards Relating to Environmental Monitoring, 1994, ASTM, Philadelphia, PA, PCN 13-600003-16 (700) Standards[5]

X2. US GEOLOGICAL SURVEY (USGS) STANDARD TECHNIQUES OF WATER RESOURCES INVESTIGATIONS (TWRI) RELATED TO SEDIMENT AND FLUVIAL HYDROLOGY

X2.1 USGS Standards Addressing Stream Discharge (Flow) and Fluvial Hydrology[6]

TWRI 3-A1 General Field and Office Procedures for Indirect Discharge Measurements, by M.A. Benson and Tate Dalrymple, 1967[6]
TWRI 3-A2 Measurement of Peak Discharge by the Slope-Area Method, by Tate Dalrymple and M.A. Benson[6]
TWRI 3-A3 Measurement of Peak Discharge at Culverts by Indirect Methods, by G.L. Bodhaine, 1968[6]
TWRI 3-A4 Measurement of Peak Discharge at Width Contractors by Indirect Methods, H.F. Matthai, 1967[6]
TWRI 3-A5 Measurement of Peak Discharge at Dams by Indirect Methods, by Harry Hulsing, 1967[6]
TWRI 3-A6 General Procedure for Gaging Streams, by R.W. Carter and Jacob Davidian, 1968[6]
TWRI 3-A7 Stage Measurements at Gaging Stations, by T.J. Buchanan and W.P. Somers, 1968[6]
TWRI 3-A8 Discharge Measurements at Gaging Stations, by T.J. Buchanan and W.P. Somers, 1969[6]
TWRI 3-A9 Measurement of Time of Travel and Dispersion in Streams by F.A. Kilpatrick, and J.F. Wilson, Jr. 1989[6]
TWRI 3-A10 Discharge Ratings at Gaging Stations, by E.J. Kennedy, 1984[6]
TWRI 3-A11 Measurement of Discharge by Moving-Boat Method, by G.F. Smoot and C.E. Novak, 1969[6]
TWRI 3-A12 Fluorometric Procedures for Dye Tracing, by J. F. Wilson, Jr., E.D. Cobb, and F.A. Kilpatrick, 1986[6]
TWRI 3-A13 Computation of Continuous Records of Streamflow, by E.J. Kennedy, 1983[6]
TWRI 3-A14 Use of Flumes in Measuring Discharge, by F.A. Kilpatrick and V.R. Schneider, 1983[6]
TWRI 3-A16 Measurement of Discharge Using Tracers, by F.A. Kilpatrick and E.D. Cobb, 1985[6]
TWRI 3-A17 Acoustic Velocity Meter Systems, by Antonius Laenen, 1985[6]
TWRI 4-A1 Some Statistical Tools in Hydrology, by H.C. Riggs, 1968[6]
TWRI 4-A2 Frequency Curves, by H.C. Riggs, 1968[6]
TWRI 4-B1 Low-Flow Investigations, by H.C. Riggs, 1972[6]
TWRI 4-B3 Regional Analyses of Streamflow Characteristics, by H.C. Riggs, 1973[6]
TWRI 8-B2 Calibration and Maintenance of Vertical-Axis Type Current Meters by G.F. Smoot and C.E. Novak, 1968[6]

[6] Available from U.S. Geological Survey-ESIC, Box 25286, MS517, Denver Federal Center, Denver, CO 80225–0046.

X2.2 USGS Standards Addressing Fluvial and Suspended Sediment

TWRI 3-C1 Fluvial Sediment Concepts, by H.P. Guy, 1970[6]
TWRI 3-C2 Field Methods of Measurement of Fluvial Sediment, by H.P. Guy and V.W. Norman, 1970[6]
TWRI 3-C3 Computation of Fluvial-Sediment Discharge, by George Porterfield, 1972[6]

X2.3 USGS Standards Addressing Laboratory and Chemical Analyses of Sediment

TWRI 5-A1 Methods for Determination of Inorganic Substances in Water and Fluvial Sediments, by M.W. Skougstad and others, editors. 1989[6]
TWRI 5-A3 Methods for the Determination of Organic Substances in Water and Fluvial Sediments, edited by R.L. Wershaw, M.J. Fishman, R. Grabbe, and L.E. Lowe, 1987[6]
TWRI 5-A5 Methods for Determination of Radioactive Substances in Water and Fluvial Sediments, by L.L. Thatcher, V.J. Janzer, and K.W. Edwards, 1977[6]
TWRI 5-A6 Quality Assurance Practices for the Chemical and Biological Analyses of Water and Fluvial Sediment, by L.C. Friedman and D.E. Erdmann, 1982[6]
TWRI 5-C1 Laboratory Theory and Methods for Sediment Analysis, by H.P. Guy, 1969[6]

REFERENCES

(**1**) *Water-Quality Monitoring in the United States, 1993 Report of the Intergovernmental Task Force on Monitoring Water Quality*, US Geological Survey, Reston, VA, ITFM, 1994.
(**2**) USDA Soil Conservation Service, *National Handbook of Water Quality Monitoring*, Part 600, USDA SCS, Washington, DC, 1994.
(**3**) *Ambient Water-Quality Monitoring in the United States, First Year Review, Evaluation, and Recommendations*, Intergovernmental Task Force on Monitoring Water Quality, US Geological Survey, Reston VA, ITFM, 1992.
(**4**) *Water-Quality Monitoring in the United States, 1993 Report of the Intergovernmental Task Force on Monitoring Water Quality*, Technical Appendices, US Geological Survey, Reston, VA, ITFM, 1994.
(**5**) *The Strategy for Water-Quality Monitoring in the United States*, Final Report of the Intergovernmental Task Force on Monitoring Water Quality, US Geological Survey, Reston, VA, ITFM, 1994.
(**6**) US EPA, *Monitoring Guidelines to Evaluate Effects of Forestry Activities on Streams in the Pacific Northwest and Alaska*, EPA/910/991/001, 1991.
(**7**) US EPA, *Guidelines for Evaluation of Agricultural Nonpoint Source Water Quality Projects*, EPA Interagency Taskforce, Washington, DC, 1981.
(**8**) Clausen, J. and Spooner, J., *Paired Watershed Study Design*, US EPA, EPA 841-F-93-009. Office of Water, Washington, DC, 1993.
(**9**) USDA, *Field Manual for Research in Agricultural Hydrology. Agricultural Handbook 224*, Washington DC, 1979.
(**10**) U.S. Geological Survey, Edwards, T. K., and Glysson, G. D., *Field Methods for Measurement of Fluvial Sediment*; Open File Report 86-531, Reston, VA, 1988.
(**11**) Saunders et al, *"Design of Networks for Monitoring Water Quality"*, Water Resource Publications, Littleton, CO, 1983.
(**12**) Water Survey of Canada, *Field Procedures for Sediment Data Collection, Volume 1 - Suspended Sediment, National Weather Services Directorate*, Ottawa, Canada, 1993.
(**13**) US Geological Survey, *Water Supply Paper 1748.*
(**14**) Federal Interagency Sedimentation Project, *A Study of Methods Used in Measurement and Analysis of Sediment Loads in Streams*, St. Anthony Falls Hydrologic Project, Minneapolis, Minn.
(**15**) Water Survey of Canada, *Field Procedures for Sediment Data Collection, Volume 2 - Bed Material Sampling*, National Weather Services Directorate, Ottawa, Canada.
(**16**) USDA, *Present and Prospective Technology for Predicting Sediment Yields and Sources*, Agricultural Research Service ARS-S-40, Oxford, MS, 1975.
(**17**) USDA Soil Conservation Service, *National Engineering Handbook-Section 3-Sedimentation*, Washington, DC, 1983.
(**18**) American Public Health Association, *Standard Methods for the Examination of Water and Wastewater*, 17th Ed., Washington, DC, 1989.
(**19**) US Environmental Protection Agency, *Methods for Chemical Analysis of Water and Wastes*, EPA 600/4-79.020. Office of Research and Development, Cincinnati, OH.

BIBLIOGRAPHY

(**1**) U.S. Army Corps of Engineers, *Sampling Design for Reservoir Water Quality Investigations*, 1987.
(**2**) U.S. Geological Survey, Rantz, S.E., et al, *Measurements and Components of Streamflow: Volume 1, Measurement of Stage Discharge; Volume 2, Compuation of Discharge*, Geological Survey Water Supply Program 2175, US GPO, Washington, DC, 1982.
(**3**) U.S. Geological Survey, *National Handbook of Recommended Methods for Water Data Acquisition*, 1977.
(**4**) Ward, R.C., Loftis, J.C., and McBride, G.B., *Design of Water Quality Monitoring Systems*, Van Nostrand Reinhold, NY, 1990.